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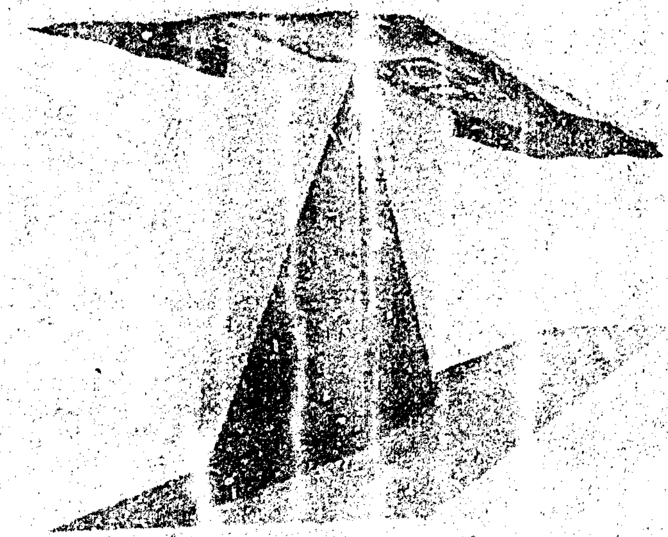
Direction-of-Arrival Calculations at VLF/LF

R. A. Pappert
L. R. Hitney



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A modification of an earlier program has been used to calculate direction-of-arrival (DOA) errors due to geomagnetic field effects at San Diego for the following VLF/LF transmitters: Annapolis (21.4 kHz), Lualualei (23.4 kHz), Cutler (24 kHz), Jim Creek (24.8 kHz), and Silver Creek (48.5 kHz). The calculations have been compared with corresponding measurements of Stang and Davis. The program can be used for both laterally homogeneous and inhomogeneous guides and allows for airborne as well as ground transmissions. Essential features of the program are reviewed and a program listing is given.

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I. INTRODUCTION

It has been known for many years that the geomagnetic field, particularly under nighttime propagation conditions, causes the normal modes in the very low frequency (VLF) and low frequency (LF) bands to be hybrid (ref. 1). That is, the modes are neither pure transverse magnetic (TM) nor pure transverse electric (TE) but rather a mixture of the two polarizations. Thus, a vertical electric dipole which radiates pure TM wave will, by virture of the radio wave interaction with the ionosphere, be a source of TE wave as well. At the ground the TE field is normally constrained, because of relatively high ground conductivity, to be very much less than the vertical electric field component. Nevertheless, the longitudinal rf magnetic field component at the ground can be significant relative to the TM component. This is possible since the longitudinal rf magnetic field component depends upon a height derivative of the TE field component. The longitudinal magnetic field component can, in the case of direction finding with loops, cause appreciable direction of arrival (DOA) error; especially in proximity to ranges where the transverse magnetic field undergoes a modal interference null. Though capability for estimating DOA errors due to the geomagnetic field has existed for sometime, the need for such calculations was minimal. New VLF and LF digital receivers under Navy development will include antenna pattern steering algorithms whose performance depends upon DOA properties of the received signal (ref. 2). This makes timely the modification of VLF/LF propagation codes for the purpose of predicting DOA errors associated with geomagnetic field effects.

Included in the present report is a modification of an early mode conversion program (ref. 3) which allows for error calculations of the DOA as a function of range for both uniform and laterally inhomogeneous guides. As with the earlier program, the present program requires waveguide modal constant inputs

as well as quantities relating to excitation factors and modal polarization. These inputs are standard, NPUNCH = 1, output of the waveguide program "MODESRCH" (ref. 4). Principal outputs of the present program are mode sum plots as a function of range for scaled transverse and longitudinal magnetic field components along with a DOA error curve. Provision is also made for plotting these quantities for fixed transmitter-receiver distance as a function of position of a horizontal inhomogeneity such as the day-night terminator. This option is useful only if the ground conductivity and geomagnetic field magnitude and orientation may be regarded as constant over the path. It is emphasized that the present program is restricted to these outputs. Should the usual electric field components be desired, the user is directed to an update of the program of reference 3 (which can be obtained from L.R. Hitney) or to the program of reference 5. The latter program can also be easily modified to accommodate DOA capability.

Reference 2 provides results of ground based measurements at San Diego of the variations in the DOA of VLF/LF signals from a number of fixed vertical transmitters. A major purpose of the present study has been to compare computer results with these measurements. Though reference 2 provides results for 24-hour periods, only the all-night and all-day cases are considered here.

In section II the origin of the rf longitudinal magnetic field component is briefly discussed and relevant formulas are summarized. A brief description of the program is given in section III. For a more complete discussion of the program the reader is referred to references 3 and 6. Results are presented in section IV and conclusions are given in section V. The Appendix contains a program listing.

II. SUMMARY OF EQUATIONS

In the following, an x, y, z rectangular coordinate system is assumed with x-z the plane of propagation and positive z directed into the ionosphere. Invariance in y is assumed. Waveguide theory applied to VLF/LF yields in the asymptotic limit (refs. 7 and 8)

$$\begin{pmatrix} H_y \\ E_y \end{pmatrix} = \frac{K}{[\sin(x/a)]^{1/2}} \sum_m \lambda_m \begin{pmatrix} h_{ym}(z) \\ e_{ym}(z) \end{pmatrix} \exp(-ik\sin(\theta_m)x) \tag{1}$$

where K is a constant, m is a mode index and,

H_y = y component of the scaled rf magnetic field intensity ($H_y = Z_o \mathcal{H}_y$ where Z_o is the characteristic impedance of free space and $\mathcal{H}_y$ is the y component of the magnetic intensity.

E_y = y component at the rf electric field.

x = range.

a = earth's radius.

z = receiver height.

h_{ym} = modal height gain for y component of the scaled rf magnetic intensity.

e_{ym} = modal height gain for y component of the rf electric field.

i = $(-1)^{1/2}$

k = free space wave number.

θ_m = modal eigenangle.

For laterally homogeneous guides λ_m is the excitation factor which depends upon the dipole transmitter altitude and orientation as well as upon functions of the eigenangle. For laterally inhomogeneous guides λ_m depends as well upon mode conversion coefficients. Details of the functional dependencies can be found, for example, in references 3 and 6. However, those details are of no particular significance in the present discussion. What is of consequence is the origin of e_y for a vertical transmitter. To understand this, use is made of the consistency relation which requires that a downgoing (d) plane wave at the ground must after ground and ionospheric reflections return to its same value upon returning to the ground. Mathematically this may be written as:

$$(1-R(\theta_m)\bar{R}(\theta_m)) \begin{pmatrix} h^d_{ym}(o) \\ e^d_{ym}(o) \end{pmatrix} = 0 \tag{2}$$

where

$$R(\theta) = \begin{pmatrix} {}_{\parallel}R_{\parallel}(\theta) & {}_{\perp}R_{\parallel}(\theta) \\ {}_{\parallel}R_{\perp}(\theta) & {}_{\perp}R_{\perp}(\theta) \end{pmatrix} \tag{3}$$

is a plane wave reflection coefficient matrix referenced to the ground and represents the reflection from everything above ground level with vacuum below it and

$$\bar{R}(\theta) = \begin{pmatrix} {}_{\parallel}\bar{R}_{\parallel}(\theta) & 0 \\ 0 & {}_{\perp}\bar{R}_{\perp}(\theta) \end{pmatrix} \tag{4}$$

is a plane wave reflection matrix referenced to the ground and represents reflection from everything below ground level with vacuum above it (i.e., the elements of $\bar{R}(\theta)$ are Fresnel reflection coefficients). Standard notation is used in the sense that the first subscript of the elements of R and $\bar{R}$ denotes the polarization of the incident wave ($\parallel$ for TM, $\perp$ for TE) and the second subscript denotes the polarization of the reflected wave. Equation (2) represents two equations. Writing out the lower of these gives

$$-{}_{\parallel}R_{\perp}(\theta_m)\;{}_{\parallel}\bar{R}_{\parallel}(\theta_m)h^d_{ym}(o) + (1-{}_{\perp}R_{\perp}(\theta_m)\,{}_{\perp}\bar{R}_{\perp}(\theta_m))e^d_{ym}(o) = 0\;. \tag{5}$$

Solving for the ratio $e^d_{ym}(o)/h^d_{ym}(o)$ from the above yields

$$\frac{e^d_{ym}(o)}{h^d_{ym}(o)} = \frac{{}_{\parallel}R_{\perp}(\theta_m)\;{}_{\parallel}\bar{R}_{\parallel}(\theta_m)}{1-{}_{\perp}R_{\perp}(\theta_m)\,{}_{\perp}\bar{R}_{\perp}\;(\theta_m)}\;. \tag{6}$$

Next it is observed that the total modal fields at the ground are by virtue of the definition of $\bar{R}$

$$h_{ym}(o) = (1 + {}_{\parallel}\bar{R}_{\parallel}(\theta_m))h^d_{ym}(o) \tag{7}$$

$$e_{ym}(o) = (1 + {}_{\perp}\bar{R}_{\perp}(\theta_m))e^d_{ym}(o)\;. \tag{8}$$

By dividing Equation (8) by Equation (7) and introducing Equation (6) it follows that

$$\frac{e_{ym}(o)}{h_{ym}(o)} = \frac{(1 + {}_{\perp}\bar{R}_{\perp}(\theta_m))}{(1 + {}_{\parallel}\bar{R}_{\parallel}(\theta_m))} \frac{{}_{\parallel}R_{\perp}(\theta_m)\ {}_{\parallel}\bar{R}_{\parallel}(\theta_m)}{1 - {}_{\perp}R_{\perp}(\theta_m)\,{}_{\perp}\bar{R}_{\perp}(\theta_m)} . \tag{9}$$

The factor in Equation (9) which involves products of the elements of R and $\bar{R}$ is a true global parameter (i.e., independent of source and receiver geometry) and is independent of the reference height chosen for those elements. This factor will be referred to as the modal polarization. The other factor in Equation (9) does depend upon the reference height chosen for R and $\bar{R}$. More generally

$$\frac{e_{ym}(z)}{h_{ym}(z)} = \left[\frac{1 + {}_{\perp}\bar{R}_{\perp}(\theta_m)}{1 + {}_{\parallel}\bar{R}_{\parallel}(\theta_m)}\right]_z \frac{{}_{\parallel}R_{\perp}(\theta_m)\ {}_{\parallel}\bar{R}_{\parallel}(\theta_m)}{1 - {}_{\perp}R_{\perp}(\theta_m)\,{}_{\perp}\bar{R}_{\perp}(\theta_m)} \tag{10}$$

where the subscript z denotes the reference height for the $\bar{R}$ reflection elements. Equation (10) gives the admixture of TE and TM components anywhere within the waveguide. It is clear that the modal polarization is proportional to the conversion coefficient, ${}_{\parallel}R_{\perp}$, so that a vertical transmitter which launches only TM wave will excite modes of hybrid structure. In the present case interest is principally in the effect of the TE admixture at the ground. Since at the ground, ${}_{\perp}\bar{R}_{\perp} \simeq -1 + \epsilon$ with $|\epsilon| << 1$, the factor $(1 + {}_{\perp}\bar{R}_{\perp}(\theta_m))_{z=0}$ constrains the e_y field to be very small relative to h_y at the ground. Nevertheless, it will be shown in Section IV that the longitudinal component of the scaled rf magnetic field,

$$H_x = \frac{1}{ik} \frac{\partial E_y}{\partial Z}\bigg|_{z = 0}, \tag{12}$$

can cause significant DOA error under nighttime propagation conditions when ${}_{\parallel}R_{\perp}$ is the largest. This is particularly true in null regions of H_y. Included in the results of Section IV are the mode sums

$$\begin{pmatrix} H_y \\ H_x \end{pmatrix} = \frac{K}{[\sin(x/a)]^{1/2}} \sum_m \lambda_m \left[\begin{pmatrix} h_{ym}(z) \\ \frac{1}{ik} \frac{\partial e_{ym}}{\partial z} \end{pmatrix}_z \right] \exp(-ik\sin(\theta_m)x) \tag{13}$$

evaluated at the ground for ground based vertical transmitters. It is remarked that h_{ym} and e_{ym} are simply linear combinations of Airy functions (or linearly related functions) and so the derivative term in Equation (13) is readily calculable. Formulas for the height gains are given, for example, in reference 6.

If the mode sums are written as

$$H_x = a_1\cos(\omega t+\delta_1) \tag{14}$$

$$H_y = a_2\cos(\omega t+\delta_2), \tag{15}$$

the end point of the magnetic intensity traces out an ellipse (see Figure 1), the properties of which are immediately obtainable from reference 9.

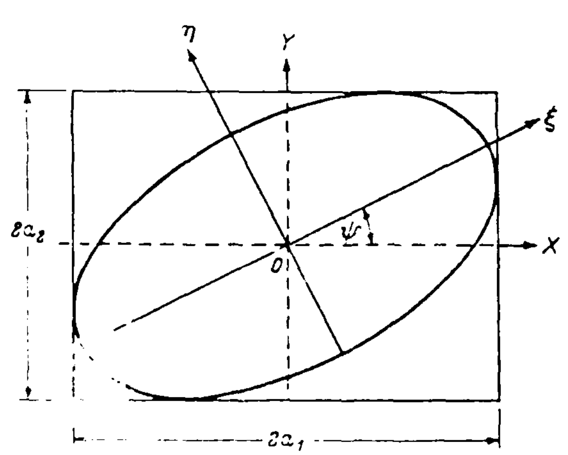

Fig. 1 MAGNETIC INTENSITY ELLIPSE.

In particular the angle ψ in Figure 1 is given by

$$\psi = 1/2 \tan^{-1}(\tan 2\alpha \cos\delta) \tag{15}$$

where

$$\tan\alpha = \frac{a_2}{a_1} \qquad o < \alpha \leq \frac{\pi}{2}, \qquad \delta = \delta_2 - \delta_1 . \tag{16}$$

Recalling that x - z is the plane of propagation with x the range coordinate and that y is the transverse coordinate in a right handed coordinate system the DOA error is

$$\chi = \pi/2 - \psi . \tag{17}$$

Positive χ implies arrival from the second quadrant of Figure 1, whereas negative χ implies arrival from the third quadrant. In section IV examples of mode sum plots for H_y and H_x are given along with plots showing the DOA error for paths examined in reference 2.

III. BRIEF PROGRAM DESCRIPTION

A. GENERAL COMMENTS

The program discussed in this section is a modification of the program discussed in reference 3 and can be used to treat either horizontally homogeneous or inhomogeneous guides. To handle horizontal inhomogeneities the waveguide is divided into a series of slabs as shown in Figure 2 below:

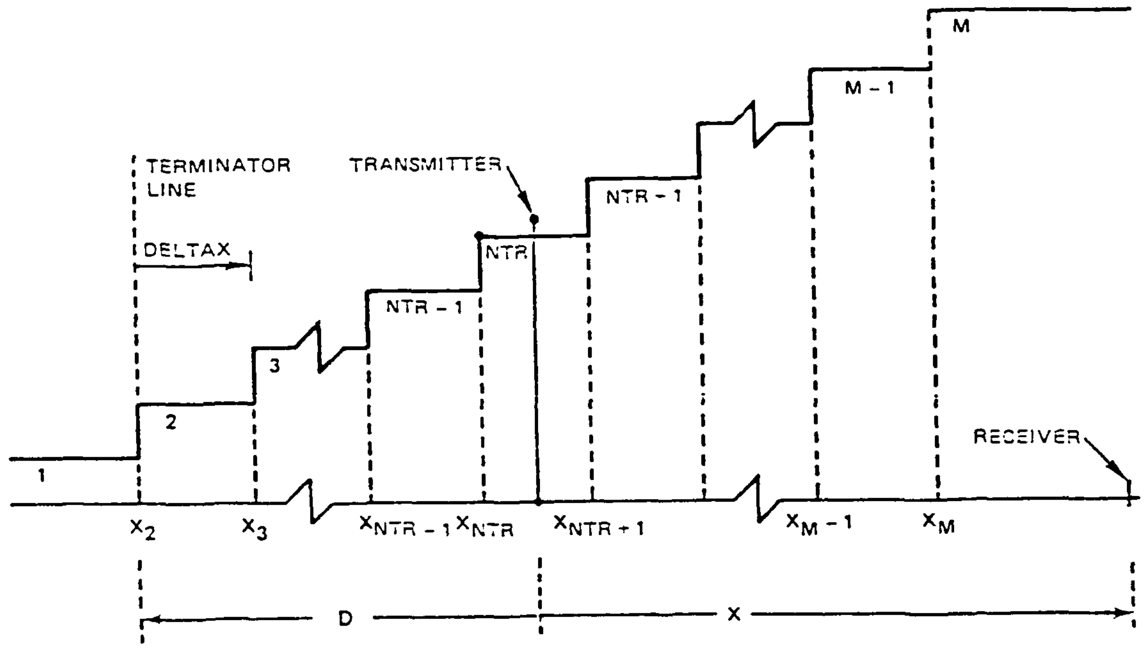

Figure 2. Mode conversion model.

In particular, Figure 2 shows the convention for slab numbering (which is reversed from that of reference 3) and a possible configuration for a terminator type lateral inhomogeneity. The transmitter is at the origin of the coordinate system and the value x_1, which is not shown, is not used in the calculations but must be assigned a value in namelist DATUM because of array dimensioning. Two options are available with the program. For each slab and

for each mode the ground eigenangles must be supplied along with four independent quantities from which electric point dipole excitation factors are determined. These quantities are supplied by the waveguide program "MODESRCH". Unlike reference 3, the number of modes can vary from slab to slab in the present program. Also, the quantity FØFR defined by Equation (5) of reference 3 (also, equivalent to Equation (9) of the present study) is calculated internally in the present program.

Mode sum plots for H_y, H_x and the DOA error can be generated as a function of range x for a fixed position of the lateral inhomogeneity or they may be plotted as a function of the tranmitter terminator distances, D, for a fixed receiver site. The latter option can be used only when the ground electrical properties and geomagnetic field magnitude and orientation can be taken as constant over the path. The plots can be generated at an arbitrary height within the waveguide for electric dipole sources of arbitrary orientation and height within the waveguide (see Figure 3).

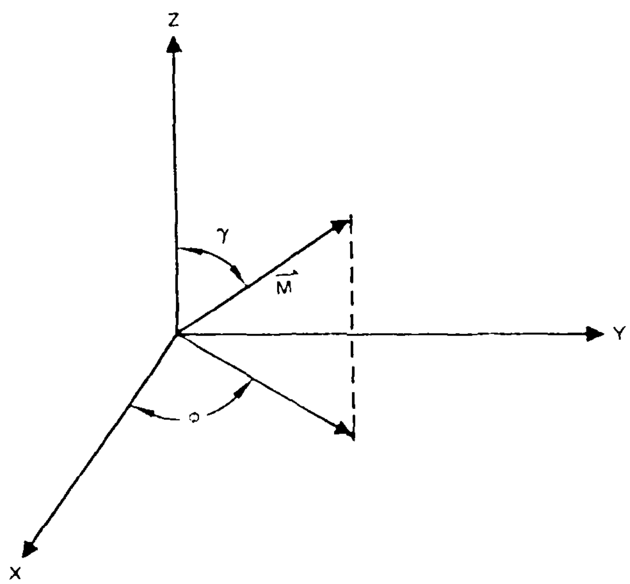

Figure 3. Dipole $\vec{M}$ orientation within the waveguide where γ is the inclination and ϕ the azimuthal orientation.

B. DESCRIPTION OF INPUT

All input to the mode conversion program is given in a data file on the standard input unit. A listing of sample input, showing the data file setup for a range calculation for a horizontally homogeneous guide is given on page 12. An input file setup for a moving terminator is given on pages 13 through 15. A sample input for a range variation in a laterally inhomogeneous guide would be similar to the sample given in reference 3.

There are two parts to the input. The first part is read in by means of a Fortran 77 namelist-directed read statement with a group name of DATUM. The following variables and arrays should be specified in the NAMELIST input.

RHOMAX - maximum range in km for which calculations are performed.

RHOMIN - minimum range in km for which calculations are performed.

DELRHO - horizontal increment in km for which successive field strengths are computed.

NRSLAB - Number of slabs in the model.

NTMAX - Number of times the transmitter terminator separation is incremented.

DELTAX - Distance in km by which transmitter-terminator separation is incremented.

SAMPLE INPUT FOR LATERALLY HOMOGENEOUS GUIDE

```
 $datum
 rhomin=25.,rhomax=10000.,delrho=25.,
 deltax=0.,ntmax=1,
 nrslab=1,
 xval=0.,
 xmin=0.,xmax=10000.,xtic=1000.,
 ymin=-90.,ymax=90.,ytic=10.,sizex=5.,sizey=6.,
 gamma=45.,phi=45.,
 zr=10.,zt=10.,
 iprnta=0,
 ipltop=2,
 iplflg=2,
 ifirst=1,
 last=1,
 $end
Lualualei to San Diego   beta=.7,hprime=87.0
R   .000 F 23.4000 A  59.000 C  40.000 M  .413E-04 S 4.000E+00 E 81.0 T 87.0
1 89.97682 -5.920991 1.17507458E-04-1.42930751E-03-2.91159674E-12 1.56223735E-13
2 89.97682 -5.920991 5.15993896E-08 2.86593256E-08 1.00046158E+00 6.63018107E-01
1 89.82555 -5.574832 2.17080335E-04-1.72104372E-03-5.10516109E-12-1.08497217E-12
2 89.82555 -5.574832-6.85928470E-08-5.32394253E-08 1.00075912E+00 6.63700819E-01
1 87.88632  -.224351-2.35080573E-04-2.65855566E-02-1.17070893E-12-1.08537094E-12
2 87.88632  -.224351 1.22134551E-07 1.42263872E-07 1.00533319E+00 6.68529391E-01
1 84.87724  -.264002 9.20612714E-04-1.01905130E-03-9.30642854E-11-3.59403197E-12
2 84.87724  -.264002-2.07534725E-07-2.50064232E-07 1.00777233E+00 6.71742201E-01
1 81.56534  -.157771-9.38259356E-04-2.64533665E-02-7.21719646E-12-7.26697782E-12
2 81.56534  -.157771 3.05091049E-07 3.59546164E-07 1.01319230E+00 6.78170621E-01
1 79.29093  -.254342 1.24309910E-03-1.29618787E-03-2.71744988E-10-1.65220084E-12
2 79.29093  -.254342-4.04487480E-07-4.83902454E-07 1.01797378E+00 6.84924006E-01
1 76.56423  -.180111-1.40988897E-03-2.33948622E-02-2.79152760E-11-2.70179695E-11
2 76.56423  -.180111 5.70840825E-07 6.39522682E-07 1.02576578E+00 6.94986641E-01
1 74.45299  -.317182 1.86981435E-03-1.98888732E-03-5.12932530E-10 1.35284353E-11
2 74.45299  -.317182-6.98896315E-07-7.95034907E-07 1.03191864E+00 7.05408871E-01
1 71.81008  -.208421-2.10860302E-03-2.16372982E-02-7.77475515E-11-7.09266951E-11
2 71.81008  -.208421 9.32243722E-07 9.67916662E-07 1.04210842E+00 7.20323980E-01
1 69.73547  -.405862 2.68813735E-03-2.99302535E-03-8.04118716E-10 5.29969506E-11
2 69.73547  -.405862-1.09387440E-06-1.15510568E-06 1.04884636E+00 7.35498965E-01
1 67.09178  -.237161-2.93348846E-03-2.01747213E-02-1.77707127E-10-1.50172735E-10
2 67.09178  -.237161 1.39038355E-06 1.30640410E-06 1.06097567E+00 7.56687820E-01
1 64.97400  -.520412 3.63010028E-03-4.30195918E-03-1.13163612E-09 1.28242014E-10
2 64.97400  -.520412-1.59059425E-06-1.52464986E-06 1.06673014E+00 7.78390706E-01
1 62.30975  -.265031-3.78178176E-03-1.87656302E-02-3.51571799E-10-2.72375650E-10
2 62.30975  -.265031 1.93094775E-06 1.60819002E-06 1.07958007E+00 8.07601869E-01

 y
 y
```

SAMPLE INPUT FOR MODELING A MOVING TERMINATOR

```
 $datum
 rhomin=3821.,rhomax=4166.,delrho=345.,
 deltax=25.,ntmax=261,
 nrslab=9,
 xval=-1525.,-1500.,-1312.5,-1187.5,-1062.5,-937.5,-812.5,-687.5,-500.,
 xmin=-1500.,xmax=5000.,xtic=500.,
 ymin=-30.,ymax=50.,ytic=10.,sizex=7.82,sizey=4.92,
 gamma=45.,phi=270.
 zr=15.,zt=15.,
 iprnta=0,
 ipltop=1,
 iplflg=1,
 ifirst=1,
 last=1,
 $end
Hprime=86 to Hprime=70
R   .000 F 21.7940 A  58.500 C  39.000 M  .431E-04 S 4.640E+00 E 81.0 T 86.0
1 89.95893 -5.614791 8.90918891E-05-2.56474130E-03-3.66113606E-12-1.41053103E-13
2 89.95893 -5.614791 7.23541476E-08 5.82935336E-08 1.04440999E+00 3.08963150E-01
1 89.73230 -5.098552 8.13409977E-04-3.18036205E-03-7.20839404E-12-1.23412988E-12
2 89.73230 -5.098552-9.77022978E-08-1.11584257E-07 1.04662442E+00 3.09465617E-01
1 86.46790  -.276901-6.97296404E-04-2.96539459E-02-2.31411700E-12-2.42465618E-12
2 86.46790  -.276901 1.52632509E-07 2.58247184E-07 1.06115580E+00 3.07544500E-01
1 83.71133  -.318972 1.78535702E-03-1.91355264E-03-1.02256321E-10-2.46968201E-12
2 83.71133  -.318972-2.50906027E-07-4.20881236E-07 1.07172537E+00 3.07309061E-01
1 80.24526  -.275711-2.00039987E-03-2.66215149E-02-1.59478784E-11-1.70393977E-11
2 80.24526  -.275711 3.87197304E-07 6.31316766E-07 1.09389603E+00 3.06244135E-01

R   .000 F 21.7940 A  58.500 C  39.000 M  .431E-04 S 4.640E+00 E 81.0 T 84.0
1 89.93198 -5.353161 1.86523030E-04-3.80378054E-03-3.72650522E-12-2.66069854E-13
2 89.93198 -5.353161 9.06502038E-08 7.63756844E-08 9.70103979E-01 2.90322542E-01
1 89.67323 -4.842402 9.74733557E-04-3.26375384E-03-9.61524870E-12-1.76274479E-12
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2 85.93787  -.315181 1.47816920E-07 2.84299375E-07 9.89267349E-01 2.90921926E-01
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2 83.22681  -.388222-2.37927182E-07-4.57677174E-07 1.00180018E+00 2.92327493E-01
1 79.73028  -.330761-2.05988088E-03-2.73547117E-02-1.47570515E-11-1.97417777E-11
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1 89.88525 -5.073801 4.76708548E-04-5.71369240E-03-3.24168990E-12-3.47774489E-13
2 89.88525 -5.073801 1.07369090E-07 9.53978301E-08 8.63476753E-01 2.74763733E-01
1 89.59141 -4.554722 9.79591976E-04-2.88872421E-03-1.31660897E-11-2.77030027E-12
2 89.59141 -4.554722-1.32362615E-07-1.66220417E-07 8.66081953E-01 2.75995642E-01
1 85.41425  -.371091-5.08478784E-04-3.22124176E-02-1.73904988E-12-2.72687819E-12
2 85.41425  -.371091 1.43651306E-07 3.02742137E-07 8.85840416E-01 2.76717037E-01
1 82.72205  -.487472 1.59731111E-03-1.18575653E-03-1.34468672E-10-9.75490175E-12
2 82.72205  -.487472-2.24028838E-07-4.83897225E-07 9.00848508E-01 2.79662967E-01
1 79.18263  -.403351-1.88347534E-03-2.82151829E-02-1.27613467E-11-2.08172975E-11
2 79.18263  -.403351 3.71068296E-07 7.55888038E-07 9.31417108E-01 2.84143299E-01

R   .000 F 21.7940 A  58.500 C  39.000 M  .431E-04 S 4.640E+00 E 81.0 T 80.0
1 89.82103 -4.781621 1.05937861E-03-8.39334913E-03-2.11253519E-12-2.83353229E-13
2 89.82103 -4.781621 1.13315721E-07 1.01717518E-07 7.26135790E-01 2.78738737E-01
1 89.46140 -4.205672 7.41320197E-04-1.97134237E-03-1.82106691E-11-4.62774090E-12
2 89.46140 -4.205672-1.38748817E-07-1.77048150E-07 7.30000734E-01 2.80761808E-01
1 84.88551  -.447061-1.71756066E-04-3.33595462E-02-1.36530576E-12-2.37677196E-12
```

```
2 84.88551  -.447061 1.44529494E-07 3.05609575E-07 7.49675095E-01 2.79543728E-01
1 82.17252  -.618432 1.24706491E-03-7.74172600E-04-1.54974325E-10-1.78294827E-11
2 82.17252  -.618432-1.94097282E-07-4.85529313E-07 7.95087934E-01 2.63119757E-01
1 78.59708  -.499461-1.50697830E-03-2.91476566E-02-9.99454252E-12-2.02260205E-11
2 78.59708  -.499461 3.56034121E-07 8.13086274E-07 7.94667065E-01 2.58789837E-01

R    .000 F 21.7940 A  58.500 C  39.000 M  .431E-04 S 4.640E+00 E 81.0 T 78.0
1 89.74937 -4.485971 1.78524549E-03-1.14039388E-02-9.32397931E-13-1.85739824E-13
2 89.74937 -4.485971 9.78692469E-08 8.47686010E-08 5.76031327E-01 3.11028749E-01
1 89.24081 -3.753632 4.48389386E-04-9.48478992E-04-2.46174071E-11-7.50462800E-12
2 89.24081 -3.753632-1.24890576E-07-1.59517882E-07 5.78858852E-01 3.12637269E-01
1 84.34246  -.546751 2.11181687E-04-3.44251283E-02-8.89651688E-13-1.74506330E-12
2 84.34246  -.546751 1.43204801E-07 2.80839743E-07 6.02452695E-01 3.11667144E-01
1 81.56769  -.801902 8.28500022E-04-5.05273812E-04-1.80112383E-10-3.04999290E-11
2 81.56769  -.801902-2.07465988E-07-4.59239033E-07 6.22810721E-01 3.15373600E-01
1 77.96826  -.635241-7.57292029E-04-3.02124228E-02-7.16761546E-12-1.57295739E-11
2 77.96826  -.635241 3.67441686E-07 7.59492764E-07 6.61270738E-01 3.18266243E-01

R    .000 F 21.7940 A  58.500 C  39.000 M  .431E-04 S 4.640E+00 E 81.0 T 76.0
1 89.67842 -4.195361 2.45779543E-03-1.41851194E-02-3.12425080E-13-1.36429022E-13
2 89.67842 -4.195361 7.04787269E-08 5.99233658E-08 4.21555966E-01 3.88745427E-01
1 88.90660 -3.171932 2.70018878E-04-3.39354476E-04-3.21954893E-11-1.11604580E-11
2 88.90660 -3.171932-9.63160147E-08-1.28835026E-07 4.29769784E-01 3.76125246E-01
1 83.78646  -.656921 5.78613428E-04-3.53961140E-02-4.17128761E-13-1.14611727E-12
2 83.78646  -.656921 1.34711897E-07 2.33643163E-07 4.48909104E-01 3.88394594E-01
1 80.88498  -.976642 4.98450419E-04-2.34734369E-04-2.11642412E-10-4.63897462E-11
2 80.88498  -.976642-1.95438730E-07-3.96136898E-07 4.70917970E-01 3.90501976E-01
1 77.29854  -.793811-2.86844370E-05-3.13108861E-02-3.75179878E-12-1.10646362E-11
2 77.29854  -.793811 3.55859243E-07 6.66429230E-07 5.09032011E-01 3.89449626E-01

R    .000 F 21.7940 A  58.500 C  39.000 M  .431E-04 S 4.640E+00 E 81.0 T 74.0
1 89.60178 -3.902511 3.09083378E-03-1.67904254E-02-9.43353129E-14-8.49416295E-14
2 89.60178 -3.902511 4.56988438E-08 3.96695583E-08 2.91040480E-01 5.15212834E-01
1 88.40370 -2.497722 1.53187531E-04-1.08900967E-04-4.13913175E-11-1.51935877E-11
2 88.40370 -2.497722-7.22185121E-08-9.34580413E-08 2.95880765E-01 5.15322745E-01
1 83.21597  -.773371 8.99333565E-04-3.62679623E-02-1.01535987E-13-7.34521602E-13
2 83.21597  -.773371 1.13296082E-07 1.78915556E-07 3.16028774E-01 5.09744406E-01
1 80.15169 -1.113712 2.94007245E-04-7.68069804E-05-2.50641397E-10-6.35519415E-11
2 80.15169 -1.113712-1.70118525E-07-3.16608464E-07 3.39071542E-01 5.05254328E-01
1 76.58773  -.971591 6.23005268E-04-3.23789045E-02-1.09145711E-12-7.29663465E-12
2 76.58773  -.971591 3.13271016E-07 5.29444264E-07 3.73405904E-01 5.06903291E-01

R    .000 F 21.7940 A  58.500 C  39.000 M  .431E-04 S 4.640E+00 E 81.0 T 72.0
1 89.50670 -3.593371 3.73883406E-03-1.93957984E-02-2.80016150E-14-4.41833222E-14
2 89.50670 -3.593371 2.83041288E-08 2.61669086E-08 2.04742640E-01 6.65039361E-01
1 87.66309 -1.927862 8.04060764E-05-3.38098434E-05-5.22675826E-11-1.98142700E-11
2 87.66309 -1.927862-5.04189011E-08-6.68672868E-08 2.10287109E-01 6.64982557E-01
1 82.62367  -.904771 1.22795266E-03-3.70658040E-02 2.93056933E-14-4.71066925E-13
2 82.62367  -.904771 8.56292814E-08 1.32001347E-07 2.27945834E-01 6.60904884E-01
1 79.40465 -1.226292 1.72982021E-04-1.48205954E-05-2.95881680E-10-8.13693696E-11
2 79.40465 -1.226292-1.35712256E-07-2.37786438E-07 2.47396663E-01 6.59889698E-01
1 75.83375 -1.174621 1.18812581E-03-3.33632752E-02 2.17520067E-13-4.73121412E-12
2 75.83375 -1.174621 2.44619088E-07 4.01201845E-07 2.78375298E-01 6.56392694E-01

R    .000 F 21.7940 A  58.500 C  39.000 M  .431E-04 S 4.640E+00 E 81.0 T 70.0
1 89.37548 -3.251751 4.42431914E-03-2.21310500E-02-8.24005764E-15-1.95039839E-14
2 89.37548 -3.251751 1.75193087E-08 1.72535923E-08 1.63431019E-01 8.03890228E-01
1 86.81053 -1.622792 3.89222732E-05-1.11819172E-05-6.52232504E-11-2.57851605E-11
```

```
2 86.81053 -1.622792-3.47190507E-08-4.73781974E-08 1.69330418E-01 8.04408669E-01
1 81.99325 -1.059281 1.60216109E-03-3.78431045E-02 4.95666469E-14-2.86521430E-13
2 81.99325 -1.059281 6.19566336E-08 9.75383330E-08 1.85555279E-01 8.03614676E-01
1 78.64407 -1.357022 9.65972431E-05-4.17938452E-07-3.47162410E-10-1.02328881E-10
2 78.64407 -1.357022-1.01884517E-07-1.78062535E-07 2.05252454E-01 8.05077076E-01
1 75.02145 -1.414181 1.72621966E-03-3.42926793E-02 5.21807912E-13-2.98834373E-12
2 75.02145 -1.414181 1.78861782E-07 3.04132669E-07 2.34394595E-01 8.06276321E-01

y
n
```

XVAL - Horizontal position in km of boundaries between adjacent slabs. These are denoted by the x_i's in Figure 2. Note that XVAL can be negative and that it is dimensioned for 25.

IFIRST - Is set to 1 in the first set of NAMELIST input. If more than one set of input is used set IFIRST = 0 in the second set.

LAST - Is set to 1 in the last set of NAMELIST input. If the user has requested plots this causes the end of file to be written on the plot tape.

IPLTOP - Plotting option flag. If IPLTOP = 1, mode sums for the scaled rf magnetic field components H_x, H_y and the DOA error are plotted as a function of transmitter-terminator distance at a given field point. If IPLTOP = 2, H_x, H_y and the DOA error are plotted as a function of range.

XMIN - Minimum value of x on plot (x either range or transmitter-terminator distance).

XMAX - Maximum value of x on plot (x either range or transmitter-terminator distance).

XTIC - Tic mark interval on x axis.

YMIN - Minimum value of y on plot (y is H_x, H_y and DOA error). Normal setting is -90.

YMAX - Maximum value of y on plot (y is H_x, H_y and DOA error). Normal setting is 90.

YTIC - Tic mark interval on y axis.

SIZEX - Size of x axis in inches.

SIZEY - Size of y axis in inches.

GAMMA - Dipole orientation relative to z axis (see Figure 3).

PHI - Dipole orientation relative to x axis (see Figure 3).

ZT - Transmitter altitude in km.

ZR - Receiver altitude in km.

INTFLG - Printing option flag. INTFLG must be set to 1 if printout of height gain integrals is required.

IPRNTA - Printing option flag. IPRNTA must be set to 1 if printout of generalized mode conversion coefficients is required.

IPLFLG - if IPLFLG $\neq$ 0 plots are determined by IPLTOP. If IPLFLG = 0 no plots are generated.

The y's or n's appearing at the end of the input files on pages 12 and 15 are in response to the questions appearing at the end of the output files on pages 27 and 37.

The second part of the input contains NPUNCH = 1 output from "MODESRCH". The output file contains the frequency in kHz and the following slab data.

SIGMA - Ground conductivity in Si/m. SIGMA is dimensioned for 25 slabs.

EPSR - Relative permittivity of the ground. EPSR is dimensioned for 25 slabs.

TOPHT - A control height in km for the upper limit on the height gain integrals (see reference 6). TOPHT is dimensioned for 25 slabs.

IDPLOT - Literal constant up to 68 characters which is printed on plots produced. For example, in the NAMELIST input data, place the card IDPLOT = "CUTLER TO SAN DIEGO PATH".

The NPUNCH = 1 output file from "MODESRCH" also contains for each mode the ground eigenangles along with four auxiliary quantities (called T1, T2, T3 and T4, see reference 3) for calculating excitation factors.

C. OUTPUT

The sample output shown on pages 19 through 27 corresponds to the input on page 12. Figure 4 is the plot output. The principal hardcopy output begins with RHO-KM, MAG(HY)-DB, MAG(HX)-DB and DOA ERROR-DEG. RHO is the range MAG(HY) = $|H_y|$, MAG(HX) = $|H_x|$ in DB above $1\mu v/m$ and DOA is the direction of

SAMPLE OUTPUT FOR LATERALLY HOMOGENEOUS GUIDE

```
$DATUM
RHOMAX =  10000.0,
RHOMIN =  25.0,
DELTAX =  0.00000000000000E+000,
NRSLAB =  1,
NTMAX =  1,
XVAL =  0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000,
DELRHO =  25.0,
IFIRST =  1,
LAST =  1,
IPLTOP =  2,
IPLFLG =  2,
XMIN =  0.000000E+00,
XMAX =  10000.0,
XTIC =  1000.0,
YMIN =  -90.0,
YMAX =  90.0,
YTIC =  10.0,
SIZEX =  5.0,
SIZEY =  6.0,
GAMMA =  45.0,
PHI =  45.0,
ZT =  10.0,
ZR =  10.0,
IPRNTA =  0,
INTFLG =  0
$end
```

Lualualei to San Diego   beta=.7,hprime=87.0

Slab 1 R .000 F 23.4000 A 59.000 C 40.000 M .000 S 4.000E+00 E 81.0 T 87.0

THETA		T1		T2		T3		T4		FOFR		TOPHI
89.977	-5.921	.118D-03	-.143D-02	-.291D-11	.156D-12	.516D-07	.287D-07	.100D+01	.663D+00	-.170D-04	.375D-04	87.0
89.826	-5.575	.217D-03	-.172D-02	-.511D-11	-.108D-11	-.686D-07	-.532D-07	.100D+01	.664D+00	.255D-04	-.431D-04	87.0
87.886	-.224	-.235D-03	-.266D-01	-.117D-11	-.109D-11	.122D-06	.142D-06	.101D+01	.669D+00	-.539D-05	.455D-05	87.0
84.877	-.264	.921D-03	-.102D-02	-.931D-10	-.359D-11	-.208D-06	-.250D-06	.101D+01	.672D+00	.338D-04	-.234D-03	87.0
81.565	-.158	-.938D-03	-.265D-01	-.722D-11	-.727D-11	.305D-06	.360D-06	.101D+01	.678D+00	-.140D-04	.110D-04	87.0
79.291	-.254	.124D-02	-.130D-02	-.272D-09	-.165D-11	-.404D-06	-.484D-06	.102D+01	.685D+00	.386D-04	-.349D-03	87.0
76.564	-.180	-.141D-02	-.234D-01	-.279D-10	-.270D-10	.571D-06	.640D-06	.103D+01	.695D+00	-.287D-04	.227D-04	87.0
74.453	-.317	.187D-02	-.199D-02	-.513D-09	.135D-10	-.699D-06	-.795D-06	.103D+01	.705D+00	.368D-04	-.386D-03	87.0
71.810	-.208	-.211D-02	-.216D-01	-.777D-10	-.709D-10	.932D-06	.968D-06	.104D+01	.720D+00	-.485D-04	.384D-04	87.0
69.735	-.406	.269D-02	-.299D-02	-.804D-09	.530D-10	-.109D-05	-.116D-05	.105D+01	.735D+00	.319D-04	-.394D-03	87.0
67.092	-.237	-.293D-02	-.202D-01	-.178D-09	-.150D-09	.139D-05	.131D-05	.106D+01	.757D+00	-.732D-04	.583D-04	87.0
64.974	-.520	.363D-02	-.430D-02	-.113D-08	.128D-09	-.159D-05	-.152D-05	.107D+01	.778D+00	.248D-04	-.391D-03	87.0

62.310 -.265 -.378D-02 -.188D-01 -.352D-09 -.272D-09 .193D-05 .161D-05 .108D+01 .808D+00 -.102D-03 .823D-04 87.0

GAMMA(DEG)= 45.0 PHI(DEG)= 45.0 ZT(KM)= 10.00 ZR(KM)= 10.00

RHO-KM	MAG(HY)-DB	MAG(HX)-DB	DOA ERROR-DEG
25.00	71.66740	47.19645	2.74230
50.00	66.95757	48.26867	2.30534
75.00	65.70000	48.11575	-2.84984
100.00	65.94413	46.78099	-5.02816
125.00	65.24773	43.89828	-4.78900
150.00	63.18882	38.26220	-3.05750
175.00	60.57584	23.28412	.21311
200.00	59.59312	33.50273	.12753
225.00	59.79551	37.33784	-3.19240
250.00	59.08715	37.26743	-4.63417
275.00	57.11247	35.04356	-2.22402
300.00	55.17791	33.48625	4.09919
325.00	54.98226	35.17102	3.17968
350.00	55.15501	36.58604	-3.25591
375.00	54.56257	36.38007	-6.95028
400.00	53.80356	34.57244	-4.17061
425.00	53.59080	31.44646	1.72029
450.00	53.24369	28.32880	3.23600
475.00	52.00952	27.34679	.45617
500.00	50.44985	27.31310	-3.61293
525.00	50.10388	26.81721	-2.92516
550.00	50.18236	25.87212	.19685
575.00	48.76371	24.58409	2.21200
600.00	44.67525	22.94579	4.27981
625.00	39.13107	21.25554	6.58955
650.00	41.42048	19.79075	1.81254
675.00	41.86361	19.27004	1.92738
700.00	38.78941	22.12901	1.76649
725.00	42.75337	25.91675	-5.85495
750.00	47.61351	28.25690	-5.81601
775.00	49.63649	28.81586	-5.18849
800.00	49.81597	27.36092	-3.54744
825.00	49.46259	23.07137	-.23697
850.00	50.10002	16.90414	1.23950
875.00	51.30544	22.24642	-.51278
900.00	51.92902	25.20647	-2.30038
925.00	51.86135	24.79284	-2.49982
950.00	51.70081	20.61537	-.96648
975.00	51.90137	4.83619	.21162
1000.00	52.11540	18.74664	-.40263
1025.00	51.91638	23.04480	-1.74951
1050.00	51.47338	23.23653	-2.21019
1075.00	51.32445	20.07961	-1.19340
1100.00	51.48270	10.42288	-.29119
1125.00	51.40879	13.28231	-.57611
1150.00	50.93456	19.32901	-1.46816
1175.00	50.58438	20.83895	-1.72658
1200.00	50.84156	20.35519	-.91484

1225.00	51.23663	19.07388	-.03937
1250.00	51.17233	18.28256	.58708
1275.00	50.73694	18.76287	1.23926
1300.00	50.58887	19.91410	1.66871
1325.00	50.98455	20.60196	1.36975
1350.00	51.33828	20.10514	.78728
1375.00	51.23180	18.72502	.54720
1400.00	50.88161	19.37252	.77047
1425.00	50.80544	22.19034	.84305
1450.00	51.02577	24.00334	.23175
1475.00	51.05230	24.01891	-.59099
1500.00	50.63639	22.15845	-.96715
1525.00	50.02036	19.52205	-.67886
1550.00	49.61143	20.53266	-.38798
1575.00	49.36560	22.95218	-.91123
1600.00	48.88462	23.67390	-1.94157
1625.00	48.04810	22.40328	-2.57419
1650.00	47.16954	19.05075	-2.18495
1675.00	46.50153	14.95611	-1.42750
1700.00	45.75887	15.51513	-1.43284
1725.00	44.66785	16.77215	-2.08329
1750.00	43.71585	15.91819	-2.32251
1775.00	43.64375	14.02518	-1.88786
1800.00	43.94242	14.47407	-1.92529
1825.00	43.85702	16.35606	-2.37024
1850.00	43.61460	17.13508	-2.26041
1875.00	43.87623	16.69878	-1.35422
1900.00	44.42009	15.95260	-.68891
1925.00	44.54139	16.12607	-.38790
1950.00	44.14115	16.89737	.20487
1975.00	43.78405	17.07365	1.22186
2000.00	43.88314	16.23312	1.75282
2025.00	44.01170	15.27830	1.70164
2050.00	43.77855	16.29053	2.00919
2075.00	43.52179	18.27494	2.97961
2100.00	43.81002	19.28176	3.36810
2125.00	44.43992	18.81991	2.57500
2150.00	44.93700	17.10133	1.64778
2175.00	45.37430	15.75187	1.32209
2200.00	46.06102	16.59953	1.33148
2225.00	46.90535	17.58372	1.08310
2250.00	47.57825	17.18725	.64693
2275.00	48.00052	15.58006	.41526
2300.00	48.34611	14.78282	.51319
2325.00	48.73292	16.12426	.64533
2350.00	49.05885	17.29521	.53353
2375.00	49.19920	17.26858	.25565
2400.00	49.20177	16.34879	.03202
2425.00	49.21022	15.44355	-.06965
2450.00	49.24235	15.06232	-.17401
2475.00	49.16658	14.48492	-.34831
2500.00	48.91394	12.95647	-.48924
2525.00	48.59632	10.50498	-.49099
2550.00	48.36596	8.38919	-.43462

2575.00	48.19297	7.78750	-.47380
2600.00	47.92335	7.64850	-.55399
2625.00	47.52505	7.49341	-.46822
2650.00	47.14250	7.56572	-.15538
2675.00	46.88370	7.57973	.16472
2700.00	46.65430	7.78575	.33504
2725.00	46.32415	9.21638	.50809
2750.00	45.93351	11.16842	.84791
2775.00	45.62033	12.28885	1.19079
2800.00	45.38404	12.11140	1.23709
2825.00	45.07602	10.70340	1.02216
2850.00	44.62740	8.90901	.83872
2875.00	44.13464	8.44797	.83934
2900.00	43.68171	8.88518	.85309
2925.00	43.16541	8.45746	.67533
2950.00	42.41728	6.48361	.38897
2975.00	41.42939	3.24941	.23864
3000.00	40.37061	1.42621	.30362
3025.00	39.33421	1.90092	.33760
3050.00	38.16378	1.14547	.15662
3075.00	36.74171	-2.27574	-.00994
3100.00	35.41099	-5.42392	.16164
3125.00	34.77007	-1.74302	.32924
3150.00	34.77986	.31992	.01694
3175.00	35.13937	.08159	-.32667
3200.00	35.96434	-.36171	-.37336
3225.00	37.16585	1.17021	-.44429
3250.00	38.28655	2.54534	-.64494
3275.00	39.09102	1.94431	-.71214
3300.00	39.68697	-1.70940	-.48420
3325.00	40.25408	-12.01122	-.13468
3350.00	40.79339	-7.93506	.05980
3375.00	41.18499	-3.79465	.10211
3400.00	41.40061	-2.73711	.18657
3425.00	41.54981	.79776	.39235
3450.00	41.73452	4.62008	.57941
3475.00	41.92940	6.78982	.62109
3500.00	42.07103	7.73983	.59836
3525.00	42.19566	8.59650	.64903
3550.00	42.40240	10.10509	.74874
3575.00	42.70412	11.65953	.75699
3600.00	43.01579	12.62803	.65041
3625.00	43.29266	13.08841	.54105
3650.00	43.58258	13.54312	.50194
3675.00	43.92730	14.27315	.48401
3700.00	44.28012	15.00275	.42203
3725.00	44.56689	15.45450	.33853
3750.00	44.77807	15.73576	.28977
3775.00	44.95826	16.12881	.27014
3800.00	45.12544	16.64615	.21771
3825.00	45.24262	17.02732	.10587
3850.00	45.27615	17.12738	-.02563
3875.00	45.24336	17.05871	-.13626
3900.00	45.18121	16.99397	-.24118

3925.00	45.08648	16.89143	-.37872
3950.00	44.92031	16.53895	-.53863
3975.00	44.67046	15.83460	-.66293
4000.00	44.37752	14.92732	-.71851
4025.00	44.08515	14.05938	-.74156
4050.00	43.78618	13.19775	-.77872
4075.00	43.45017	12.01454	-.80487
4100.00	43.08910	10.29466	-.75139
4125.00	42.75443	8.25947	-.60910
4150.00	42.46621	6.45811	-.44896
4175.00	42.19046	4.94348	-.31556
4200.00	41.90434	3.39545	-.17620
4225.00	41.63517	2.58928	-.01131
4250.00	41.40548	3.21964	.12048
4275.00	41.17921	3.89425	.16751
4300.00	40.90772	3.76009	.17252
4325.00	40.60022	3.25059	.20999
4350.00	40.30236	3.17653	.27878
4375.00	40.01664	3.34088	.31993
4400.00	39.70124	3.09765	.33167
4425.00	39.35862	2.70617	.37845
4450.00	39.07121	3.05521	.47375
4475.00	38.91873	3.96037	.53431
4500.00	38.90697	4.60592	.50841
4525.00	39.02464	4.93329	.44862
4550.00	39.29764	5.38572	.39617
4575.00	39.72614	6.03993	.31224
4600.00	40.23751	6.49284	.17484
4625.00	40.75378	6.51542	.03525
4650.00	41.25146	6.28211	-.05752
4675.00	41.73110	6.09741	-.11736
4700.00	42.16932	5.94472	-.18170
4725.00	42.52925	5.51059	-.24854
4750.00	42.80034	4.61857	-.28458
4775.00	43.00309	3.45913	-.27847
4800.00	43.15633	2.44783	-.25872
4825.00	43.25587	1.67959	-.25432
4850.00	43.29188	.79437	-.25955
4875.00	43.27367	-.42783	-.25255
4900.00	43.22430	-1.71263	-.23313
4925.00	43.15524	-2.60770	-.22183
4950.00	43.06119	-3.25362	-.22423
4975.00	42.94230	-4.22426	-.22005
5000.00	42.81710	-5.69715	-.19530
5025.00	42.70420	-6.91711	-.16648
5050.00	42.60073	-6.85814	-.15711
5075.00	42.49188	-6.19059	-.16342
5100.00	42.37580	-5.66648	-.16484
5125.00	42.26440	-4.64545	-.16077
5150.00	42.15974	-2.63135	-.17512
5175.00	42.04379	-.45266	-.22263
5200.00	41.89724	1.30611	-.29150
5225.00	41.71756	2.74504	-.36725
5250.00	41.51075	4.12454	-.45755

5275.00	41.27240	5.46346	-.58077
5300.00	40.98830	6.59142	-.73737
5325.00	40.65309	7.42209	-.90801
5350.00	40.27722	8.03288	-1.07985
5375.00	39.87064	8.54245	-1.26121
5400.00	39.42796	8.96056	-1.46167
5425.00	38.94027	9.19613	-1.66620
5450.00	38.41849	9.19272	-1.84284
5475.00	37.89347	9.00301	-1.97499
5500.00	37.39071	8.72498	-2.07086
5525.00	36.91911	8.37513	-2.13040
5550.00	36.49382	7.86920	-2.12171
5575.00	36.15332	7.14258	-2.01568
5600.00	35.93303	6.24039	-1.83223
5625.00	35.83246	5.25361	-1.61720
5650.00	35.82935	4.16880	-1.38838
5675.00	35.91076	2.86431	-1.14749
5700.00	36.06593	1.29581	-.92039
5725.00	36.26434	-.40740	-.73665
5750.00	36.46849	-2.20286	-.58620
5775.00	36.66456	-4.52330	-.43417
5800.00	36.86310	-8.34987	-.26936
5825.00	37.07220	-16.31509	-.11177
5850.00	37.28611	-20.12394	.02487
5875.00	37.50303	-9.73786	.15043
5900.00	37.73827	-4.69759	.27167
5925.00	38.00980	-1.26926	.37190
5950.00	38.31924	1.19283	.43156
5975.00	38.65657	2.99734	.45349
6000.00	39.01590	4.41025	.45304
6025.00	39.39524	5.59585	.43551
6050.00	39.78472	6.57743	.39765
6075.00	40.16638	7.32681	.34435
6100.00	40.52642	7.86712	.29003
6125.00	40.86048	8.27168	.24387
6150.00	41.16555	8.58568	.20306
6175.00	41.43275	8.78558	.16271
6200.00	41.65174	8.83191	.12595
6225.00	41.81904	8.73487	.10005
6250.00	41.93806	8.54448	.08619
6275.00	42.01186	8.28352	.07862
6300.00	42.03982	7.92032	.07361
6325.00	42.02219	7.42267	.07446
6350.00	41.96459	6.81112	.08572
6375.00	41.87516	6.13188	.10648
6400.00	41.75893	5.39048	.13323
6425.00	41.61806	4.56721	.16737
6450.00	41.45708	3.72237	.21458
6475.00	41.28397	3.02719	.27605
6500.00	41.10435	2.60952	.34520
6525.00	40.91737	2.43906	.41555
6550.00	40.71974	2.46289	.48750
6575.00	40.51143	2.68609	.56312
6600.00	40.29426	3.04735	.63781

6625.00	40.06582	3.39362	.70249
6650.00	39.81897	3.61718	.75305
6675.00	39.54773	3.71164	.79193
6700.00	39.25061	3.69500	.82027
6725.00	38.92699	3.53832	.83436
6750.00	38.57413	3.19773	.83253
6775.00	38.19139	2.68823	.82125
6800.00	37.78647	2.08826	.80976
6825.00	37.37438	1.46559	.80154
6850.00	36.97148	.84477	.79637
6875.00	36.59524	.29372	.79951
6900.00	36.27029	-.02883	.82032
6925.00	36.02731	-.03320	.85851
6950.00	35.88932	.17058	.89967
6975.00	35.86073	.42592	.92949
7000.00	35.93131	.67433	.94433
7025.00	36.08460	.89981	.94390
7050.00	36.29867	1.05074	.92463
7075.00	36.54640	1.07159	.88601
7100.00	36.80268	.96383	.83547
7125.00	37.05112	.77235	.78171
7150.00	37.28236	.51969	.72729
7175.00	37.48877	.18708	.67118
7200.00	37.66399	-.22844	.61557
7225.00	37.80664	-.66868	.56572
7250.00	37.92111	-1.05313	.52361
7275.00	38.01334	-1.35198	.48555
7300.00	38.08731	-1.58106	.44695
7325.00	38.14643	-1.72932	.40697
7350.00	38.19645	-1.73640	.36648
7375.00	38.24466	-1.54931	.32345
7400.00	38.29610	-1.17079	.27352
7425.00	38.35225	-.63759	.21453
7450.00	38.41307	.02167	.14794
7475.00	38.47848	.78810	.07533
7500.00	38.54686	1.62584	-.00378
7525.00	38.61349	2.47670	-.08967
7550.00	38.67229	3.28863	-.17965
7575.00	38.71876	4.04039	-.26961
7600.00	38.75021	4.73363	-.35759
7625.00	38.76359	5.36653	-.44413
7650.00	38.75460	5.92312	-.52932
7675.00	38.71954	6.38761	-.61103
7700.00	38.65716	6.75964	-.68684
7725.00	38.56805	7.04940	-.75635
7750.00	38.45272	7.26119	-.82049
7775.00	38.31152	7.38826	-.87889
7800.00	38.14629	7.42431	-.92927
7825.00	37.96115	7.37328	-.96950
7850.00	37.76112	7.24353	-.99890
7875.00	37.55084	7.03639	-1.01667
7900.00	37.33544	6.74855	-1.02012
7925.00	37.12189	6.38758	-1.00619
7950.00	36.91799	5.97905	-.97468

7975.00	36.72943	5.55376	-.92857
8000.00	36.55875	5.13335	-.87109
8025.00	36.40698	4.73683	-.80427
8050.00	36.27509	4.39502	-.73099
8075.00	36.16283	4.14067	-.65647
8100.00	36.06770	3.98201	-.58592
8125.00	35.98650	3.90129	-.52169
8150.00	35.91798	3.87886	-.46408
8175.00	35.86311	3.90138	-.41375
8200.00	35.82380	3.94975	-.37136
8225.00	35.80304	4.00066	-.33543
8250.00	35.80624	4.04599	-.30263
8275.00	35.84089	4.09815	-.27081
8300.00	35.91354	4.17127	-.24010
8325.00	36.02767	4.26749	-.21071
8350.00	36.18415	4.38689	-.18159
8375.00	36.38207	4.53809	-.15218
8400.00	36.61757	4.72743	-.12408
8425.00	36.88268	4.94373	-.09950
8450.00	37.16663	5.16372	-.07900
8475.00	37.45832	5.36785	-.06175
8500.00	37.74751	5.54319	-.04716
8525.00	38.02473	5.67537	-.03513
8550.00	38.28152	5.74767	-.02481
8575.00	38.51153	5.74944	-.01455
8600.00	38.71087	5.67986	-.00297
8625.00	38.87737	5.54115	.01022
8650.00	39.00972	5.33201	.02512
8675.00	39.10769	5.05173	.04240
8700.00	39.17265	4.70877	.06296
8725.00	39.20732	4.32043	.08672
8750.00	39.21474	3.90289	.11261
8775.00	39.19767	3.46577	.13944
8800.00	39.15887	3.01776	.16649
8825.00	39.10140	2.57152	.19301
8850.00	39.02815	2.13637	.21757
8875.00	38.94115	1.70898	.23846
8900.00	38.84153	1.27655	.25453
8925.00	38.72988	.82604	.26505
8950.00	38.60622	.34248	.26905
8975.00	38.46959	-.20043	.26527
9000.00	38.31791	-.84044	.25292
9025.00	38.14869	-1.61632	.23219
9050.00	37.95982	-2.56467	.20357
9075.00	37.74945	-3.73317	.16721
9100.00	37.51587	-5.19954	.12317
9125.00	37.25767	-7.08314	.07237
9150.00	36.97468	-9.54809	.01670
9175.00	36.66853	-12.72807	-.04168
9200.00	36.34244	-15.81708	-.10066
9225.00	36.00112	-15.20696	-.15764
9250.00	35.65107	-11.98579	-.20903
9275.00	35.30086	-9.17100	-.25078
9300.00	34.96067	-7.06581	-.27951

9325.00	34.64120	-5.49782	-.29276
9350.00	34.35282	-4.32666	-.28880
9375.00	34.10516	-3.46830	-.26724
9400.00	33.90611	-2.87158	-.23056
9425.00	33.76011	-2.49788	-.18431
9450.00	33.66722	-2.31463	-.13523
9475.00	33.62391	-2.29905	-.08919
9500.00	33.62442	-2.44000	-.05080
9525.00	33.66175	-2.73201	-.02354
9550.00	33.72827	-3.16813	-.00926
9575.00	33.81677	-3.74143	-.00756
9600.00	33.92160	-4.45300	-.01638
9625.00	34.03904	-5.31516	-.03340
9650.00	34.16688	-6.34618	-.05647
9675.00	34.30410	-7.56767	-.08341
9700.00	34.45087	-9.00870	-.11204
9725.00	34.60828	-10.68081	-.14098
9750.00	34.77739	-12.41676	-.17002
9775.00	34.95845	-13.46797	-.19954
9800.00	35.15072	-12.77204	-.22967
9825.00	35.35270	-10.70961	-.26029
9850.00	35.56223	-8.37833	-.29144
9875.00	35.77628	-6.25027	-.32327
9900.00	35.99095	-4.41457	-.35557
9925.00	36.20202	-2.85577	-.38758
9950.00	36.40538	-1.53673	-.41833
9975.00	36.59714	-.42198	-.44697
10000.00	36.77363	.51508	-.47271

If this is the hp 7550 plotter and you want auto feed,
then set up the plotter, load a sheet and answer y:
Do you want auto feed?
Set up plotter, enter rotation (y/n) when ready

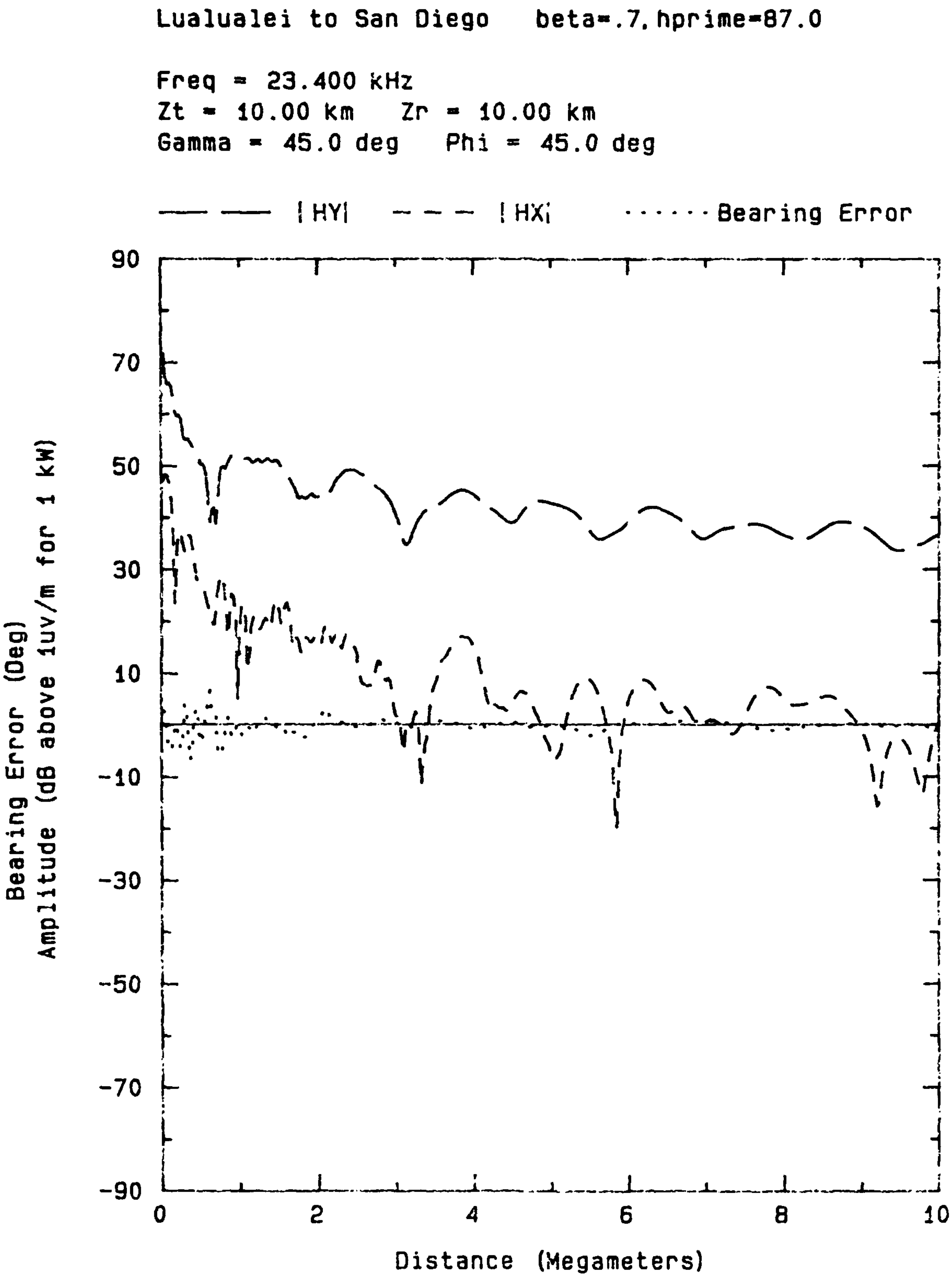

Figure 4. Plot output for laterally homogeneous guide sample input.

arrival error in degrees. The sample output shown on pages 30 through 37 corresponds to the input which begins on page 13 and Figure 5 is the plot output. In this case the transmitter-terminator distance is the distance D on Figure 2.

SAMPLE OUTPUT FOR MOVING TERMINATOR

```
$DATUM
RHOMAX =  4166.0,
RHOMIN =  3821.0,
DELTAX =  25.0,
NRSLAB =  9,
NIMAX =  261,
XVAL =  -1525.0, -1500.0, -1312.500000000000000, -1187.500000000000000,
-1062.500000000000000, -937.500000000000000, -812.500000000000000,
-687.500000000000000, -500.0, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000, 0.00000000000000E+000,
0.00000000000000E+000, 0.00000000000000E+000,
DELRHO =  345.0,
IFIRST =  1,
LAST =  1,
IPLTOP =  1,
IPLFLG =  1,
XMIN =  -1500.0,
XMAX =  5000.0,
XTIC =  500.0,
YMIN =  -30.0,
YMAX =  50.0,
YTIC =  10.0,
SIZEX =  7.82000017,
SIZEY =  4.92000008,
GAMMA =  45.0,
PHI =  270.0,
ZT =  15.0,
ZR =  15.0,
IPRNTA =  0,
INTFLG =  0
$end
```

Hprime=86 to Hprime=70

```
Slab  1 R   .000 F 21.7940 A  58.500 C  39.000 M  .000 S 4.640E+00 E 81.0 T 86.0
   THETA            T1                      T2                      T3                     T4                       FOFR             TOPHT
 89.959 -5.615   .891D-04 -.256D-02   -.366D-11 -.141D-12    .724D-07  .583D-07   .104D+01  .309D+00   -.217D-04  .290D-04   86.0
 89.732 -5.099   .813D-03 -.318D-02   -.721D-11 -.123D-11   -.977D-07 -.112D-06   .105D+01  .309D+00    .256D-04 -.373D-04   86.0
 86.468  -.277  -.697D-03 -.297D-01   -.231D-11 -.242D-11    .153D-06  .258D-06   .106D+01  .308D+00   -.882D-05  .494D-05   86.0
 83.711  -.319   .179D-02 -.191D-02   -.102D-09 -.247D-11   -.251D-06 -.421D-06   .107D+01  .307D+00    .522D-04 -.180D-03   86.0
 80.245  -.276  -.200D-02 -.266D-01   -.159D-10 -.170D-10    .387D-06  .631D-06   .109D+01  .306D+00   -.247D-04  .127D-04   86.0

Slab  2 R   .000 F 21.7940 A  58.500 C  39.000 M  .000 S 4.640E+00 E 81.0 T 84.0
   THETA            T1                      T2                      T3                     T4                       FOFR             TOPHT
 89.932 -5.353   .187D-03 -.380D-02   -.373D-11 -.266D-12    .907D-07  .764D-07   .970D+00  .290D+00   -.189D-04  .248D-04   84.0
 89.673 -4.842   .975D-03 -.326D-02   -.962D-11 -.176D-11   -.116D-06 -.139D-06   .972D+00  .291D+00    .294D-04 -.443D-04   84.0
 85.938  -.315  -.677D-03 -.310D-01   -.207D-11 -.272D-11    .148D-06  .284D-06   .989D+00  .291D+00   -.928D-05  .457D-05   84.0
 83.227  -.388   .179D-02 -.156D-02   -.117D-09 -.495D-11   -.238D-06 -.458D-06   .100D+01  .292D+00    .513D-04 -.212D-03   84.0
 79.730  -.331  -.206D-02 -.274D-01   -.148D-10 -.197D-10    .380D-06  .699D-06   .103D+01  .294D+00   -.264D-04  .119D-04   84.0
```

Slab 3 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 82.0

THETA		T1		T2		T3		T4		FOFR		TOPHT
89.885	-5.074	.477D-03	-.571D-02	-.324D-11	-.348D-12	.107D-06	.954D-07	.863D+00	.275D+00	-.150D-04	.200D-04	82.0
89.591	-4.555	.980D-03	-.289D-02	-.132D-10	-.277D-11	-.132D-06	-.166D-06	.866D+00	.276D+00	.377D-04	-.586D-04	82.0
85.414	-.371	-.508D-03	-.322D-01	-.174D-11	-.273D-11	.144D-06	.303D-06	.886D+00	.277D+00	-.947D-05	.431D-05	82.0
82.722	-.487	.160D-02	-.119D-02	-.134D-09	-.975D-11	-.224D-06	-.484D-06	.901D+00	.280D+00	.546D-04	-.262D-03	82.0
79.183	-.403	-.188D-02	-.282D-01	-.128D-10	-.208D-10	.371D-06	.756D-06	.931D+00	.284D+00	-.275D-04	.113D-04	82.0

Slab 4 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 80.0

THETA		T1		T2		T3		T4		FOFR		TOPHT
89.821	-4.782	.106D-02	-.839D-02	-.211D-11	-.283D-12	.113D-06	.102D-06	.726D+00	.279D+00	-.103D-04	.148D-04	80.0
89.461	-4.206	.741D-03	-.197D-02	-.182D-10	-.463D-11	-.139D-06	-.177D-06	.730D+00	.281D+00	.555D-04	-.913D-04	80.0
84.886	-.447	-.172D-03	-.334D-01	-.137D-11	-.238D-11	.145D-06	.306D-06	.750D+00	.280D+00	-.918D-05	.429D-05	80.0
82.173	-.618	.125D-02	-.774D-03	-.155D-09	-.178D-10	-.194D-06	-.486D-06	.795D+00	.263D+00	.621D-04	-.351D-03	80.0
78.597	-.499	-.151D-02	-.291D-01	-.999D-11	-.202D-10	.356D-06	.813D-06	.795D+00	.259D+00	-.285D-04	.107D-04	80.0

Slab 5 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 78.0

THETA		T1		T2		T3		T4		FOFR		TOPHT
89.749	-4.486	.179D-02	-.114D-01	-.932D-12	-.186D-12	.979D-07	.848D-07	.576D+00	.311D+00	-.594D-05	.951D-05	78.0
89.241	-3.754	.448D-03	-.948D-03	-.246D-10	-.750D-11	-.125D-06	-.160D-06	.579D+00	.313D+00	.866D-04	-.173D-03	78.0
84.342	-.547	.211D-03	-.344D-01	-.890D-12	-.175D-11	.143D-06	.281D-06	.602D+00	.312D+00	-.813D-05	.421D-05	78.0
81.568	-.802	.829D-03	-.505D-03	-.180D-09	-.305D-10	-.207D-06	-.459D-06	.623D+00	.315D+00	.639D-04	-.515D-03	78.0
77.968	-.635	-.757D-03	-.302D-01	-.717D-11	-.157D-10	.367D-06	.759D-06	.661D+00	.318D+00	-.254D-04	.115D-04	78.0

Slab 6 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 76.0

THETA		T1		T2		T3		T4		FOFR		TOPHT
89.678	-4.195	.246D-02	-.142D-01	-.312D-12	-.136D-12	.705D-07	.599D-07	.422D+00	.389D+00	-.327D-05	.553D-05	76.0
88.907	-3.172	.270D-03	-.339D-03	-.322D-10	-.112D-10	-.963D-07	-.129D-06	.430D+00	.376D+00	.942D-04	-.359D-03	76.0
83.786	-.657	.579D-03	-.354D-01	-.417D-12	-.115D-11	.135D-06	.234D-06	.449D+00	.388D+00	-.654D-05	.391D-05	76.0
80.885	-.977	.498D-03	-.235D-03	-.212D-09	-.464D-10	-.195D-06	-.396D-06	.471D+00	.391D+00	-.146D-04	-.802D-03	76.0
77.299	-.794	-.287D-04	-.313D-01	-.375D-11	-.111D-10	.356D-06	.666D-06	.509D+00	.389D+00	-.213D-04	.113D-04	76.0

Slab 7 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 74.0

THETA		T1		T2		T3		T4		FOFR		TOPHT
89.602	-3.903	.309D-02	-.168D-01	-.943D-13	-.849D-13	.457D-07	.397D-07	.291D+00	.515D+00	-.180D-05	.305D-05	74.0
88.404	-2.498	.153D-03	-.109D-03	-.414D-10	-.152D-10	-.722D-07	-.935D-07	.296D+00	.515D+00	-.251D-04	-.628D-03	74.0
83.216	-.773	.899D-03	-.363D-01	-.102D-12	-.735D-12	.113D-06	.179D-06	.316D+00	.510D+00	-.485D-05	.324D-05	74.0
80.152	-1.114	.294D-03	-.768D-04	-.251D-09	-.636D-10	-.170D-06	-.317D-06	.339D+00	.505D+00	-.279D-03	-.115D-02	74.0
76.588	-.972	.623D-03	-.324D-01	-.109D-11	-.730D-11	.313D-06	.529D-06	.373D+00	.507D+00	-.162D-04	.999D-05	74.0

Slab 8 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 72.0

THETA		T1		T2		T3		T4		FOFR		TOPHT
89.507	-3.593	.374D-02	-.194D-01	-.280D-13	-.442D-13	.283D-07	.262D-07	.205D+00	.665D+00	-.103D-05	.166D-05	72.0
87.663	-1.928	.804D-04	-.338D-04	-.523D-10	-.198D-10	-.504D-07	-.669D-07	.210D+00	.665D+00	-.242D-03	-.926D-03	72.0
82.624	-.905	.123D-02	-.371D-01	.293D-13	-.471D-12	.856D-07	.132D-06	.228D+00	.661D+00	-.348D-05	.243D-05	72.0
79.405	-1.226	.173D-03	-.148D-04	-.296D-09	-.814D-10	-.136D-06	-.238D-06	.247D+00	.660D+00	-.656D-03	-.145D-02	72.0
75.834	-1.175	.119D-02	-.334D-01	.218D-12	-.473D-11	.245D-06	.401D-06	.278D+00	.656D+00	-.117D-04	.775D-05	72.0

Slab 9 R .000 F 21.7940 A 58.500 C 39.000 M .000 S 4.640E+00 E 81.0 T 70.0

THETA		T1		T2		T3		T4		FOFR		TOPHT
89.375	-3.252	.442D-02	-.221D-01	-.824D-14	-.195D-13	.175D-07	.173D-07	.163D+00	.804D+00	-.597D-06	.911D-06	70.0
86.811	-1.623	.389D-04	-.112D-04	-.652D-10	-.258D-10	-.347D-07	-.474D-07	.169D+00	.804D+00	-.504D-03	-.136D-02	70.0
81.993	-1.059	.160D-02	-.378D-01	.496D-13	-.287D-12	.620D-07	.975D-07	.186D+00	.804D+00	-.250D-05	.174D-05	70.0

78.644	-1.357	.966D-04	-.418D-06	-.347D-09	-.102D-09	-.102D-06	-.178D-06	.205D+00	.805D+00	-.105D-02	-.185D-02	70.0
75.021	-1.414	.173D-02	-.343D-01	.522D-12	-.299D-11	.179D-06	.304D-06	.234D+00	.806D+00	-.858D-05	.565D-05	70.0

GAMMA(DEG)= 45.0 PHI(DEG)= 270.0 ZT(KM)= 15.00 ZR(KM)= 15.00

RHO-KM	MAG(HY)-DB	MAG(HX)-DB	DOA ERROR-DEG
-1500.00	34.47892	-3.81974	-.69616
-1475.00	34.47892	-3.81974	-.69616
-1450.00	34.47892	-3.81974	-.69616
-1425.00	34.47892	-3.81974	-.69616
-1400.00	34.47892	-3.81974	-.69616
-1375.00	34.47892	-3.81974	-.69616
-1350.00	34.47892	-3.81974	-.69616
-1325.00	34.47892	-3.81974	-.69616
-1300.00	34.47892	-3.81974	-.69616
-1275.00	34.47892	-3.81974	-.69616
-1250.00	34.47892	-3.81974	-.69616
-1225.00	34.47892	-3.81974	-.69616
-1200.00	34.47892	-3.81974	-.69616
-1175.00	34.47892	-3.81974	-.69616
-1150.00	34.47892	-3.81974	-.69616
-1125.00	34.47892	-3.81974	-.69616
-1100.00	34.47892	-3.81974	-.69616
-1075.00	34.47892	-3.81974	-.69616
-1050.00	34.47892	-3.81974	-.69616
-1025.00	34.47892	-3.81974	-.69616
-1000.00	34.58644	-3.39803	-.72150
-975.00	34.56483	-3.43329	-.72077
-950.00	34.53733	-3.50123	-.71771
-925.00	34.50733	-3.59941	-.71228
-900.00	34.47756	-3.72460	-.70460
-875.00	34.44984	-3.87256	-.69496
-850.00	34.42490	-4.03793	-.68382
-825.00	34.40250	-4.21414	-.67179
-800.00	34.46198	-3.94278	-.68802
-775.00	34.42507	-4.10970	-.67781
-750.00	34.38156	-4.30081	-.66631
-725.00	34.33237	-4.51125	-.65387
-700.00	34.27830	-4.73488	-.64086
-675.00	34.27860	-4.44543	-.66126
-650.00	34.21058	-4.64109	-.65124
-625.00	34.13583	-4.86098	-.63985
-600.00	34.05593	-5.10078	-.62725
-575.00	33.97232	-5.35457	-.61368
-550.00	33.95747	-5.07095	-.63026
-525.00	33.86533	-5.28489	-.61990
-500.00	33.76840	-5.52065	-.60792
-475.00	33.66802	-5.77332	-.59447
-450.00	33.56533	-6.03609	-.57973
-425.00	33.52674	-5.72958	-.59425
-400.00	33.41534	-5.93593	-.58357
-375.00	33.29926	-6.15699	-.57130
-350.00	33.17956	-6.38672	-.55754

-325.00	33.05709	-6.61704	-.54244
-300.00	33.00925	-6.14768	-.55929
-275.00	32.87444	-6.30345	-.54927
-250.00	32.73381	-6.46226	-.53800
-225.00	32.58839	-6.61775	-.52553
-200.00	32.43914	-6.76233	-.51199
-175.00	32.37304	-6.21965	-.52520
-150.00	32.20744	-6.28857	-.51792
-125.00	32.03511	-6.35397	-.50991
-100.00	31.85725	-6.41173	-.50120
-75.00	31.67506	-6.45740	-.49185
-50.00	31.48966	-6.48633	-.48194
-25.00	31.30198	-6.49385	-.47158
.00	31.22661	-5.80880	-.48201
25.00	31.02061	-5.75371	-.48032
50.00	30.80734	-5.69380	-.47901
75.00	30.58796	-5.62780	-.47817
100.00	30.36367	-5.55442	-.47792
125.00	30.13564	-5.47246	-.47835
150.00	29.90497	-5.38080	-.47957
175.00	29.67266	-5.27841	-.48173
200.00	29.43956	-5.16442	-.48495
225.00	29.20638	-5.03811	-.48941
250.00	28.97364	-4.89896	-.49531
275.00	28.74168	-4.74665	-.50289
300.00	28.51074	-4.58110	-.51241
325.00	28.28094	-4.40246	-.52423
350.00	28.05239	-4.21108	-.53873
375.00	27.82526	-4.00758	-.55639
400.00	27.59991	-3.79276	-.57774
425.00	27.37694	-3.56760	-.60339
450.00	27.15735	-3.33328	-.63400
475.00	26.94262	-3.09108	-.67027
500.00	26.73477	-2.84242	-.71286
525.00	26.53647	-2.58880	-.76235
550.00	26.35102	-2.33178	-.81915
575.00	26.18228	-2.07295	-.88332
600.00	26.03459	-1.81395	-.95451
625.00	25.91257	-1.55638	-1.03177
650.00	25.82083	-1.30186	-1.11347
675.00	25.76359	-1.05196	-1.19731
700.00	25.74438	-.80824	-1.28034
725.00	25.76568	-.57217	-1.35922
750.00	25.82862	-.34521	-1.43050
775.00	25.93295	-.12872	-1.49098
800.00	26.07697	.07601	-1.53797
825.00	26.25779	.26775	-1.56963
850.00	26.47158	.44536	-1.58495
875.00	26.71389	.60783	-1.58382
900.00	26.97998	.75419	-1.56686
925.00	27.26514	.88363	-1.53525
950.00	27.56487	.99543	-1.49057
975.00	27.87505	1.08898	-1.43458
1000.00	28.19202	1.16383	-1.36912

1025.00	28.51265	1.21963	-1.29600
1050.00	28.83429	1.25619	-1.21694
1075.00	29.15475	1.27347	-1.13349
1100.00	29.47231	1.27157	-1.04707
1125.00	29.78561	1.25076	-.95892
1150.00	30.09359	1.21147	-.87011
1175.00	30.39548	1.15431	-.78155
1200.00	30.69072	1.08005	-.69402
1225.00	30.97888	.98966	-.60813
1250.00	31.25965	.88430	-.52437
1275.00	31.53284	.76534	-.44312
1300.00	31.79826	.63436	-.36463
1325.00	32.05580	.49322	-.28906
1350.00	32.30538	.34400	-.21650
1375.00	32.54699	.18912	-.14694
1400.00	32.78067	.03128	-.08034
1425.00	33.00654	-.12645	-.01662
1450.00	33.22483	-.28067	.04435
1475.00	33.43587	-.42760	.10271
1500.00	33.64011	-.56316	.15859
1525.00	33.83810	-.68299	.21214
1550.00	34.03043	-.78256	.26353
1575.00	34.21774	-.85725	.31293
1600.00	34.40061	-.90257	.36053
1625.00	34.57953	-.91430	.40656
1650.00	34.75480	-.88873	.45129
1675.00	34.92646	-.82279	.49506
1700.00	35.09430	-.71428	.53824
1725.00	35.25776	-.56198	.58129
1750.00	35.41600	-.36571	.62470
1775.00	35.56795	-.12636	.66901
1800.00	35.71233	.15418	.71477
1825.00	35.84782	.47317	.76255
1850.00	35.97311	.82712	.81289
1875.00	36.08706	1.21204	.86629
1900.00	36.18871	1.62361	.92322
1925.00	36.27742	2.05739	.98407
1950.00	36.35285	2.50902	1.04915
1975.00	36.41496	2.97430	1.11872
2000.00	36.46397	3.44931	1.19295
2025.00	36.50023	3.93047	1.27198
2050.00	36.52418	4.41456	1.35587
2075.00	36.53618	4.89864	1.44470
2100.00	36.53640	5.38011	1.53851
2125.00	36.52473	5.85654	1.63742
2150.00	36.50074	6.32573	1.74158
2175.00	36.46365	6.78556	1.85123
2200.00	36.41234	7.23403	1.96667
2225.00	36.34551	7.66918	2.08827
2250.00	36.26175	8.08911	2.21645
2275.00	36.15969	8.49200	2.35163
2300.00	36.03822	8.87613	2.49416
2325.00	35.89657	9.23989	2.64426
2350.00	35.73457	9.58186	2.80195

2375.00	35.55272	9.90083	2.96693
2400.00	35.35236	10.19586	3.13847
2425.00	35.13578	10.46629	3.31531
2450.00	34.90633	10.71180	3.49546
2475.00	34.66844	10.93242	3.67610
2500.00	34.42772	11.12856	3.85346
2525.00	34.19083	11.30097	4.02273
2550.00	33.96544	11.45079	4.17808
2575.00	33.75994	11.57949	4.31287
2600.00	33.58307	11.68885	4.42006
2625.00	33.44341	11.78088	4.49282
2650.00	33.34870	11.85781	4.52543
2675.00	33.30517	11.92193	4.51421
2700.00	33.31679	11.97555	4.45834
2725.00	33.38474	12.02083	4.36035
2750.00	33.50712	12.05972	4.22604
2775.00	33.67901	12.09377	4.06377
2800.00	33.89283	12.12406	3.88339
2825.00	33.82295	12.34650	3.92673
2850.00	34.05833	12.36170	3.78486
2875.00	34.32481	12.37288	3.64615
2900.00	34.61314	12.38093	3.51491
2925.00	34.91408	12.38642	3.39380
2950.00	35.21879	12.38955	3.28421
2975.00	35.51905	12.39013	3.18666
3000.00	35.80741	12.38754	3.10109
3025.00	35.80135	12.72306	3.27852
3050.00	36.02739	12.73106	3.25771
3075.00	36.24107	12.73586	3.24202
3100.00	36.43967	12.73587	3.22945
3125.00	36.62080	12.72923	3.21832
3150.00	36.58416	13.02928	3.40890
3175.00	36.71295	13.04480	3.43024
3200.00	36.82752	13.05337	3.44825
3225.00	36.92765	13.05240	3.46113
3250.00	37.01318	13.03935	3.46756
3275.00	36.93267	13.22947	3.61049
3300.00	36.97881	13.23831	3.63212
3325.00	37.01476	13.23430	3.64550
3350.00	37.04158	13.21498	3.64924
3375.00	37.06020	13.17819	3.64248
3400.00	36.94730	13.22190	3.71595
3425.00	36.94286	13.20258	3.71704
3450.00	36.93530	13.16653	3.70746
3475.00	36.92597	13.11227	3.68664
3500.00	36.91593	13.03874	3.65459
3525.00	36.80669	12.96543	3.66759
3550.00	36.78914	12.92045	3.64808
3575.00	36.77417	12.86070	3.61966
3600.00	36.76253	12.78607	3.58276
3625.00	36.75459	12.69681	3.53831
3650.00	36.67435	12.53713	3.51171
3675.00	36.66478	12.49488	3.49053
3700.00	36.65882	12.44437	3.46484

3725.00	36.65658	12.38615	3.43524
3750.00	36.65790	12.32096	3.40251
3775.00	36.66238	12.24976	3.36753
3800.00	36.66947	12.17367	3.33130
3825.00	36.62451	11.95320	3.28659
3850.00	36.62451	11.95320	3.28659
3875.00	36.62451	11.95320	3.28659
3900.00	36.62451	11.95320	3.28659
3925.00	36.62451	11.95320	3.28659
3950.00	36.62451	11.95320	3.28659
3975.00	36.62451	11.95320	3.28659
4000.00	36.62451	11.95320	3.28659
4025.00	36.62451	11.95320	3.28659
4050.00	36.62451	11.95320	3.28659
4075.00	36.62451	11.95320	3.28659
4100.00	36.62451	11.95320	3.28659
4125.00	36.62451	11.95320	3.28659
4150.00	36.62451	11.95320	3.28659
4175.00	36.62451	11.95320	3.28659
4200.00	36.62451	11.95320	3.28659
4225.00	36.62451	11.95320	3.28659
4250.00	36.62451	11.95320	3.28659
4275.00	36.62451	11.95320	3.28659
4300.00	36.62451	11.95320	3.28659
4325.00	36.62451	11.95320	3.28659
4350.00	36.62451	11.95320	3.28659
4375.00	36.62451	11.95320	3.28659
4400.00	36.62451	11.95320	3.28659
4425.00	36.62451	11.95320	3.28659
4450.00	36.62451	11.95320	3.28659
4475.00	36.62451	11.95320	3.28659
4500.00	36.62451	11.95320	3.28659
4525.00	36.62451	11.95320	3.28659
4550.00	36.62451	11.95320	3.28659
4575.00	36.62451	11.95320	3.28659
4600.00	36.62451	11.95320	3.28659
4625.00	36.62451	11.95320	3.28659
4650.00	36.62451	11.95320	3.28659
4675.00	36.62451	11.95320	3.28659
4700.00	36.62451	11.95320	3.28659
4725.00	36.62451	11.95320	3.28659
4750.00	36.62451	11.95320	3.28659
4775.00	36.62451	11.95320	3.28659
4800.00	36.62451	11.95320	3.28659
4825.00	36.62451	11.95320	3.28659
4850.00	36.62451	11.95320	3.28659
4875.00	36.62451	11.95320	3.28659
4900.00	36.62451	11.95320	3.28659
4925.00	36.62451	11.95320	3.28659
4950.00	36.62451	11.95320	3.28659
4975.00	36.62451	11.95320	3.28659
5000.00	36.62451	11.95320	3.28659

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If this is the hp 7550 plotter and you want auto feed,
then set up the plotter, load a sheet and answer y:
Do you want auto feed?
Set up plotter, enter rotation (y/n) when ready
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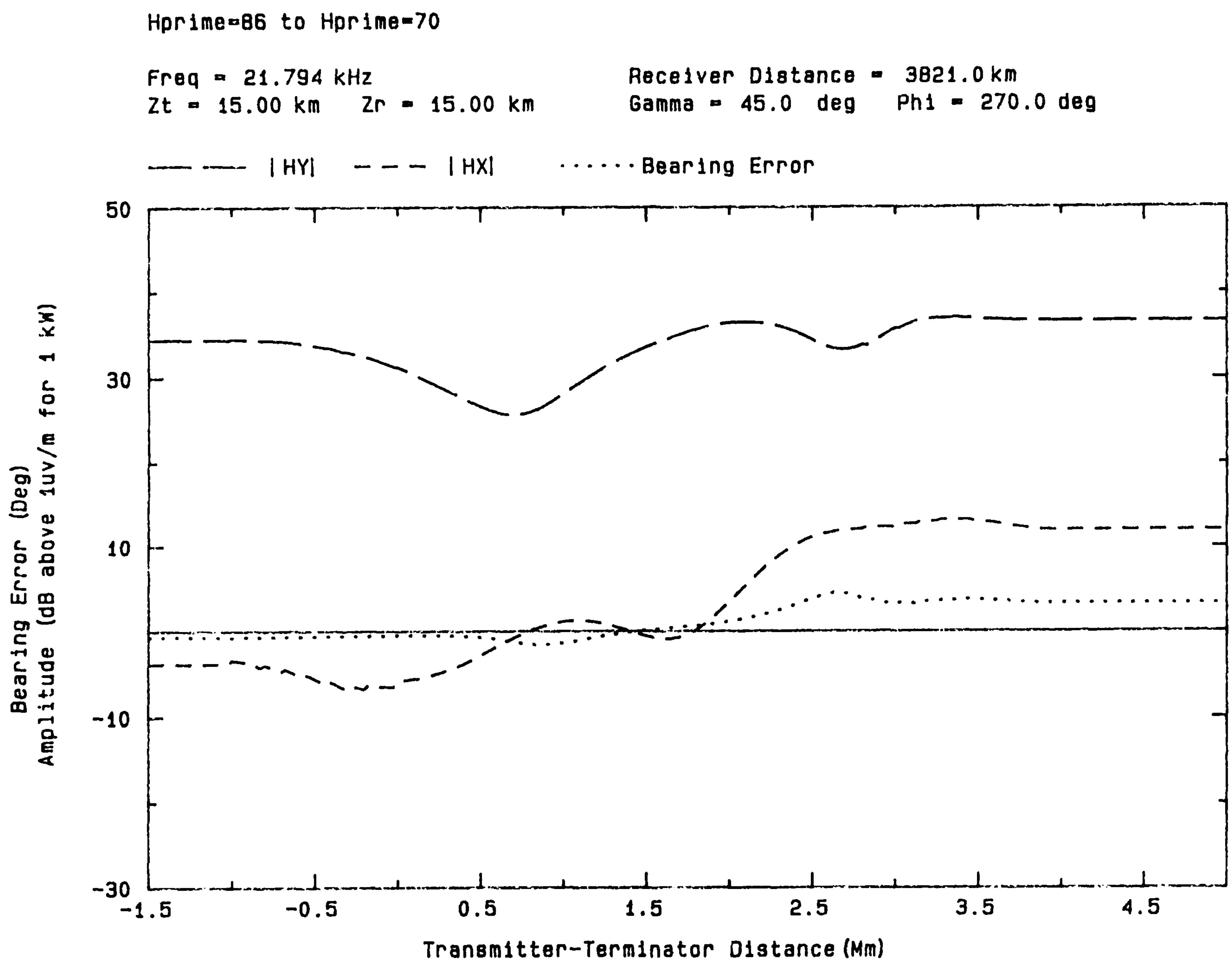

Figure 5. Plot output for moving terminator sample input.

IV. RESULTS

In the following section day and night comparisons are given between calculations and variations in the DOA at San Diego measured in reference 2 for the following VLF/LF transmitters: Annapolis, Lualualei, Cutler, Jim Creek and Silver Creek.

A. DOA RESULTS FOR ANNAPOLIS TO SAN DIEGO - DAY

Annapolis transmits at 21.4 kHz. Geomagnetic midpath parameters and midpath values for the ground conductivity and dielectric constant used for the calculations are:

azimuth from magnetic north = 249°,

codip = 23°,

$|\vec{B}|$ = magnitude of the earth's magnetic induction vector = 0.537 x 10^{-4} w-/m^2.

σ = ground conductivity = 10^{-2} S/M.

ϵ = earth's dielectric constant = 15.

Figure 6 shows measured histograms for two days in April 1987 when daylight prevailed over the entire path. The horizontal scale is such that the true bearing should be 45° with values greater than 45° corresponding to signals arriving from south of the true DOA and values less than 45° corresponding to signals arriving from north of the true DOA. The theoretical spread, discussed subsequently, is indicated by the arrows on the top and although it encompasses the region when most observations occurred it does underestimate the observed spread indicating that perhaps some off path ground or ionospheric scatter is playing a role. The theoretical spread is less than 2°. To arrive at the theoretical spread, waveguide calculations were performed for

exponential profiles characterized in the notation of Wait and Spies (ref 10), by:

$$\beta = 0.3 \text{ km}^{-1},\ 0.5 \text{ km}^{-1} \begin{cases} h' = 70 \text{ km} \\ h' = 72 \text{ km} \\ h' = 74 \text{ km} \end{cases} . \tag{18}$$

On the basis of a previous study with exponential profiles (ref. 11) these profiles appear to be reasonable bounds for daytime propagation. The DOA for these profiles at the Annapolis-San Diego range (taken to be 3705 km) was then used to determine the spread. Clearly this is simply one of many procedures for determining the spread but, unless noted otherwise, it is the method used for spread comparisons throughout this section.

An illustrative example of mode sum behavior as a function of range is shown in Figure 7. Shown are mode sum plots for the scaled transverse and longitudinal magnetic intensities H_y and H_x respectively. Also shown is DOA (or bearing) error. The plot is for the $\beta = 0.3$ km^{-1}, $h' = 74$ km profile and shows that even under daytime conditions large errors are possible ($\simeq 50°$) at ranges $\lesssim 1$ Mm. Examination of such curves for the six profiles considered showed DOA errors less than about 3° at ranges greater than about 1.5 Mm.

B. DOA RESULTS FOR ANNAPOLIS TO SAN DIEGO - NIGHT

Figure 8 shows measured histograms for two days in April when nighttime prevailed over the entire path. To arrive at the theoretical spread, waveguide calculations were performed for the following exponential profiles:

$$\beta = 0.4\ \mathrm{km}^{-1},\ 0.5\ \mathrm{km}^{-1},\ 0.7\ \mathrm{km}^{-1} \begin{cases} h' = 86\ \mathrm{km} \\ h' = 87\ \mathrm{km}. \\ h' = 88\ \mathrm{km} \end{cases} \tag{19}$$

Again they were chosen on the basis of the study of exponential profiles given in reference 11. The theoretical spread of about 12° is in reasonable agreement with the observed spreads though the calculations indicate arrivals from the south of the true DOA whereas the measurements indicate substantial numbers of arrivals from the north.

An example of mode sum behavior as a function of range is shown in Figure 9. The possibility of DOA errors in excess of 70° at ranges < 2 Mm is clearly evident. Examination of mode sum plots and DOA's for the nine cases considered indicates that errors ≈ 30° are quite possible at select ranges in excess of about 2.5 Mm.

C. DOA RESULTS FOR LUALUALEI TO SAN DIEGO - DAY

Lualualei transmits at 23.4 kHz. Geomagnetic midpath parameters and midpath values for the ground conductivity and dielectric constant used for the calculations are:

azimuth from magnetic north = 59°

codip = 40°

$|\vec{B}| = 0.413 \times 10^{-4} \mathrm{w/m}^2$

$\sigma = 4$ S/M

$\epsilon = 81$.

Figures 10 and 11 show daytime histograms of the DOA's measured during April of 1987. The true bearing should be 45° with values greater than 45° corresponding to signals arriving from north of the true DOA and values less than 45° corresponding to signals arriving from south of the true DOA. The theoretical spread of about 2° calculated for the transmitter receiver separation of 4211 km using the profiles specified in Equations (18) is in quite good agreement with the 4/10, 4/11 and 4/12 data. The 4/1 data indicates a somewhat larger spread with the preponderance of measurements indicating arrivals from more southerly directions than predicted.

Of the six profiles used to determine the spread the only one which indicated an appreciable effect was the $\beta = 0.5\ km^{-1}$, $h' = 74$ km case shown in Figure 12. In that instance it will be seen that a deep null in HY occurs close to the receiving site. The spread indicated on Figures 10 and 11 could clearly be increased by allowing for a reception range about the receiving site and/or a more densely selected set of profiles. This points out the subjective nature of the comparisons.

D. DOA RESULTS FOR LUALUALEI TO SAN DIEGO - NIGHT

Figures 13 and 14 show nighttime histograms of the DOA's for the four days in April. The profiles specified in Equations (19) were used to determine the theoretical spreads. The lower spread was calculated as described for the previous cases. The small spread is singular among all of the nighttime cases considered. It reflects in some measure the smooth propagation characteristics of easterly propagation. If a loose tolerance of $\pm$ 200 km in range about the receiving site is permitted then the theoretical spread is given by the curve marked "calculated spread*". The reason for the difference in the spread is evident from Figure 15 which shows the mode sum and DOA error for

the $\beta = 0.7 \text{ km}^{-1}$, $h' = 86$ km profile. The error peak which occurs at about 4400 km is responsible for the augmented spread.

E. DOA RESULTS FOR CUTLER TO SAN DIEGO - DAY

Cutler transmits at 24.0 kHz. Geomagnetic midpath parameters and midpath values for the ground conductivity and dielectric constant used for the calculations are:

azimuth from magnetic north = 245.5°

codip = 19.3°

$|\vec{B}| = 0.553 \times 10^{-4}$ w/m^2

$\sigma = 10^{-2}$ S/m

$\epsilon = 15.$

Figure 16 shows daytime histograms of the DOA's measured during two days in March 1987. The true bearing should be 45° with values greater than 45° corresponding to signals arriving from south of the true DOA and values less than 45° corresponding to signals arriving from north of the true DOA. The theoretical spread, calculated for a transmitter-receiver distance of 4454 km, is somewhat less than 2° and appears to be consistent with the bulk of the measurements. An example of the mode sum and DOA plots for this case is shown in Figure 17.

F. DOA RESULTS FOR CUTLER TO SAN DIEGO - NIGHT

Figure 18 shows nighttime histograms of the DOA 's for three days in March of 1987. The profiles specified in Equations (19) were used to determine the theoretical spreads. The rather large calculated spread in excess of 30°

results from a null in $|HY|$ close to the receiving site (4454 km) for the β = 0.5 km^{-1}, h' = 88 km profile. This is shown in Figure 19. The theoretical spread is larger than indicated by the measurements. The theoretical result predicts all arrivals from south of the true bearing while the measurements show a substantial number of arrivals from the north.

G. DOA RESULTS FOR JIM CREEK TO SAN DIEGO - DAY

Jim Creek transmits at 24.8 kHz. Geomagnetic midpath parameters and midpath values for the ground conductivity and dielectric constant used for the calculation are:

azimuth from magnetic north = 149°

codip = 25°

$|\vec{B}| = .518 \times 10^{-4}\ w/m^2$

$\sigma = 10^{-2}$ S/M

$\epsilon = 15.$

Figure 20 shows daytime histograms of the DOA's measured during three days in April 1987. The true bearing should be 45° with values greater than 45° corresponding to signals arriving from east of the true DOA and values less than 45° corresponding to signals arriving from west of the true DOA. The calculated spread for a transmitter receiver distance of 1767 km is about 1°. Though it underestimates the total measured spread, the latter is quite peaked indicating a spread for the bulk of the measurements of about 1°. An example of the mode sum and DOA plots for this case is shown in Figure 21.

H. DOA RESULTS FOR JIM CREEK TO SAN DIEGO - NIGHT

Figures 22 and 23 show nighttime histograms of the DOA's for five days in April 1987 and one day in December 1986. The profiles specified in Equation (19) were used to determine the theoretical spread which is over 40°. The histograms range from spreads of about 20° to about 40°. Figure 24 is an example of the bearing error behavior with range. This path has been cited as having the most extreme behavior (ref. 2). The reason for this is probably the relatively short path length (1767 km) rather than anything peculiar about the north south path. It is clear from the nighttime mode sum plots (e.g., Figures 9, 15, 19 and 24) that the most severe problems, except for isolated instances, occur for ranges < 2000 km.

I. DOA RESULTS FOR SILVER CREEK TO SAN DIEGO - DAY

Silver Creek transmits at 48.5 kHz. It is the sole LF frequency considered in this study. Geomagnetic midpath parameters and midpath values for the ground conductivity and dielectric constant used for the calculations are:

azimuth from magnetic north = 227.7°

codip = 24.9°

$|\vec{B}| = 0.523 \times 10^{-4} w/m^2$

$\sigma = 10^{-2} s/m$

$\epsilon = 15.$

At this LF frequency the study reported in reference 11 indicates that the following daytime profiles cover the range of interest

$$\beta = 0.3\ \text{km}^{-1},\ 0.5\ \text{km} \begin{cases} h' = 70\ \text{km} \\ h' = 73\ \text{km}. \\ h' = 75\ \text{km} \end{cases} \tag{20}$$

Figures 25, 26 and 27 show daytime histograms for six days of measurement in November 1986 and one day in December 1986. Values greater than 45° correspond to signals arriving from south of the true bearing and values less than 45° correspond to signals arriving from north of the true bearing. The theoretical spread of about 2° calculated on the basis of the above profiles at a range of 1989 km is consistent with the observations. The calculated result indicates arrivals from the north whereas the measurements indicate arrivals from both north and south of the true bearing. A sample mode sum and DOA plot for this case is given in Figure 28.

J. DOA RESULTS FOR SILVER CREEK TO SAN DIEGO - NIGHT

Figures 29, 30 and 31 show nighttime histograms for the seven days of measurements. Under nighttime conditions at this LF frequency the following six profiles have been used.

$$\beta = 0.7\ \text{km}^{-1},\ 0.8\ \text{km}^{-1},\ 0.9\ \text{km}^{-1},\ 1.0\ \text{km}^{-1},\ 1.1\ \text{km}^{-1},\ 1.2\ \text{km}^{-1} \Big\}\ h = 88\ \text{km}. \tag{21}$$

Again they were chosen on the basis of the study of exponential profiles given in reference 11.

The theoretical spread based on these profiles indicates a preponderance of arrivals from the north with the spread being over 50°. The measurements indicate spreads ranging between about 20° and 30° with substantial arrivals

from both the North and South. The reason for the large calculated spread is the deep null in |HY| at about 2 Mm shown in Figure 32. Failure of the measurements to show such an effect could indicate that either the profiles were inadequate or that too few modes were used. With respect to the latter, in all cases the modal search rectangle was 60° to 90° for the real part of the eigenangle and 0 to -4° for the imaginary part. Examination of the mode set in this instance indicates that the dominant mode would be at least 30 dB higher than the first neglected mode at the receiving site so that profile inadequacy seems the more likely explanation.

V. CONCLUSIONS

A modification of an earlier program has been used to calculate DOA errors due to geomagnetic field effects at San Diego for the following VLF/LF transmitters: Annapolis (21.4 kHz), Lualualei (23.4 kHz), Cutler (24 kHz), Jim Creek (24.8 kHz) and Silver Creek (48.5 kHz). Calculated spreads of the DOA have been based on a selection of best fit exponential profiles determined in a previous study (ref. 11). This is subjective in the sense that it is just one of many procedures that could be used to determine the DOA spread. The calculations have been compared with corresponding variations in the DOA reported in reference 2. Calculated daytime spreads were about 2°. Measured daytime spreads were somewhat larger than this, though the bulk of the measurements usually is confined to a range of several degrees. In agreement with measurements and expectations, the nighttime calculated DOA spreads were much greater than the daytime spreads. A quantitative comparison between calculated and measured nighttime spreads is shown below:

	Calculated Nighttime Spread	Measured Nighttime Spread
Annapolis	≈ 11°	≈ 25°
Lualualei	≈ 2°	≈ 8°
Cutler	≈ 32°	≈ 20°
Jim Creek	≈ 42°	≈ 22° to ≈ 42°
Silver Creek	≈ 53°	≈ 33° to 47°

In addition, the nighttime calculations for Annapolis and Cutler yield an excessive number (relative to measurement) of arrivals from the south, the calculations for Jim Creek indicate an excessive number from the east and the

calculations for Silver Creek indicate an excessive number of arrivals from the north.

Generally there is no obvious trend in DOA variation with frequency in the VLF band, though on the basis of the calculations the nighttime DOA variation is expected to be more severe for the LF frequency than for the VLf frequencies at ranges > 5000 km. Calculations and measurements indicate that the nighttime westerly paths are subject to more DOA variation than the single easterly path considered. This is believed to be due to geomagnetic field effects and not to conductivity differences for the easterly and westerly paths (ref. 12). Reference 2 singles out Jim Creek as a path of excessive DOA variation. On the basis of the calculations it is believed that this is because of the relatively short path (1767 km) and not because of peculiarities associated with north-south propagation.

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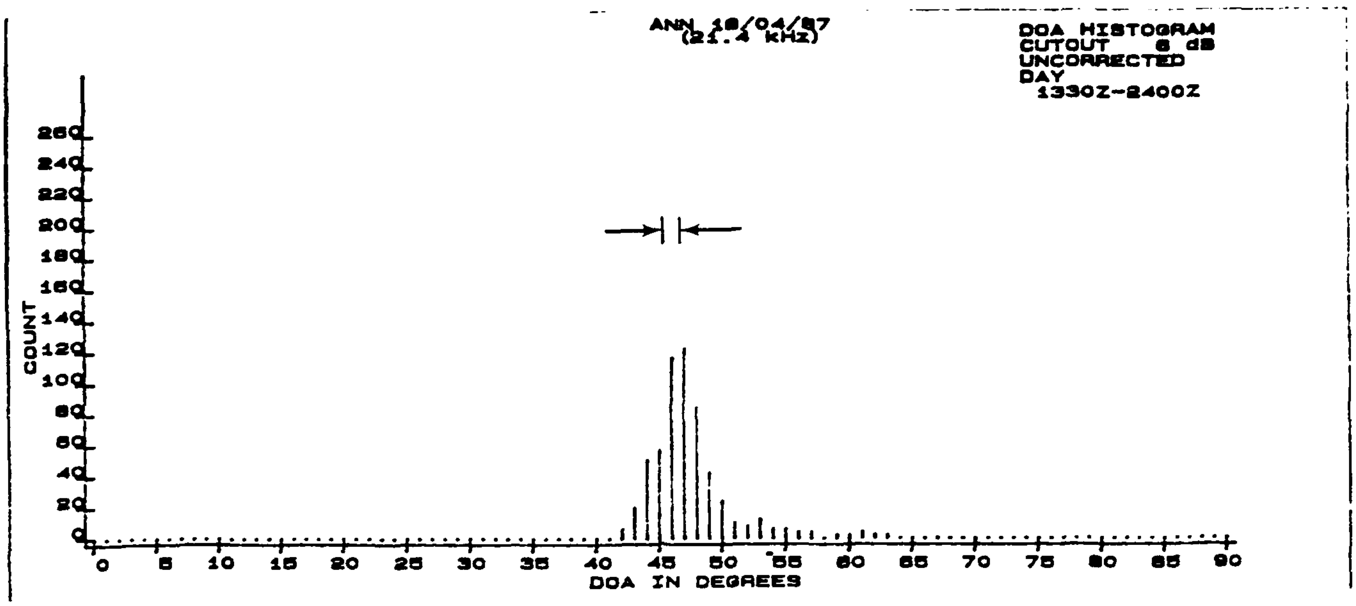


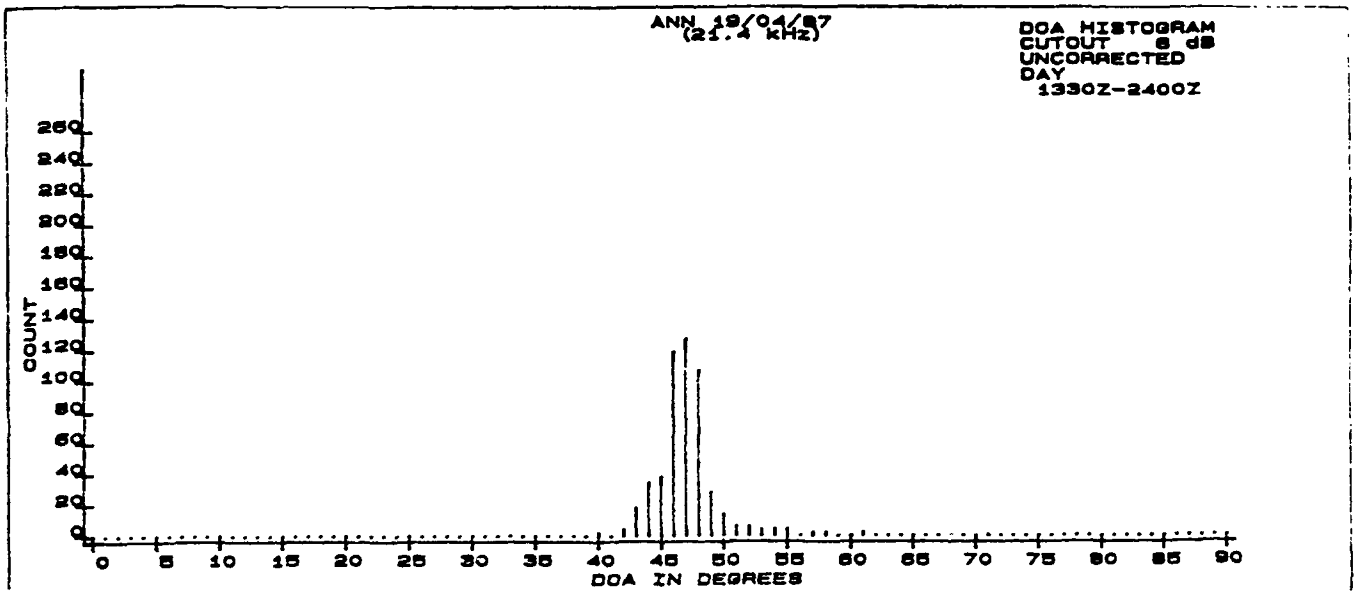


Figure 6. Histograms for Annapolis to San Diego - Day.

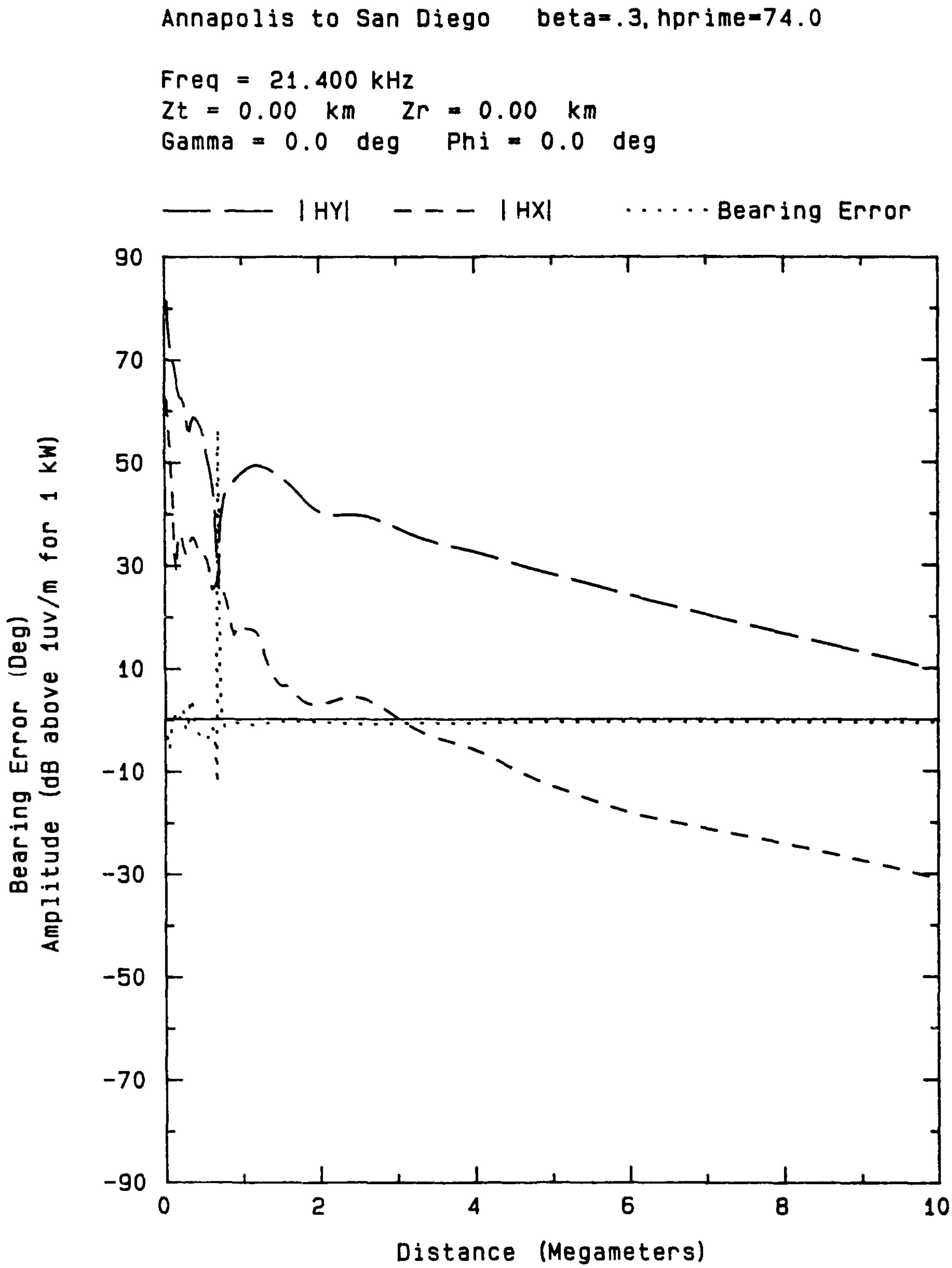
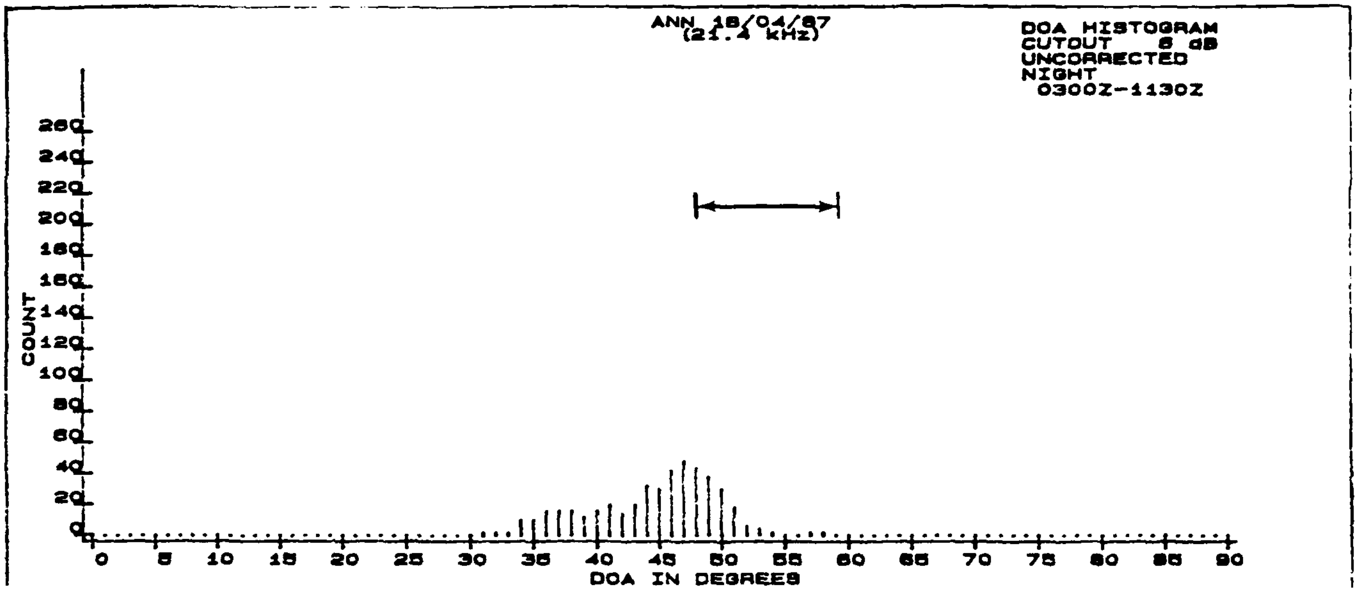


Figure 7. Sample range plot for Annapolis to San Diego - Day.



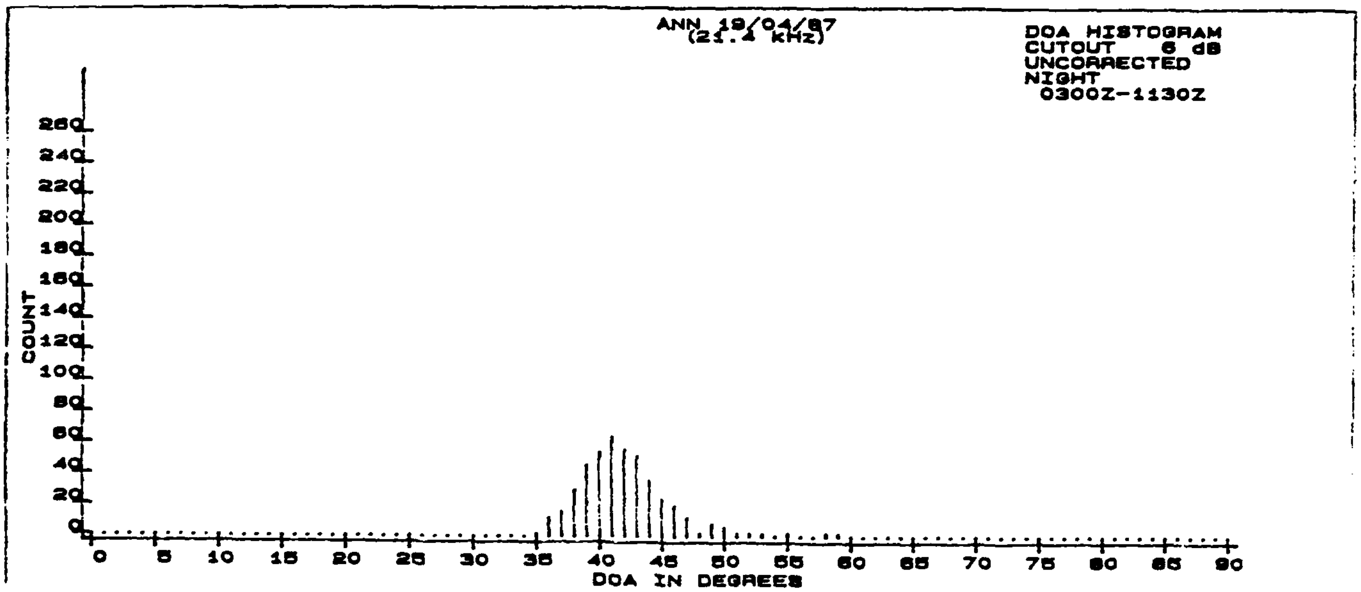


Figure 8. Histograms for Annapolis to San Diego - Night.

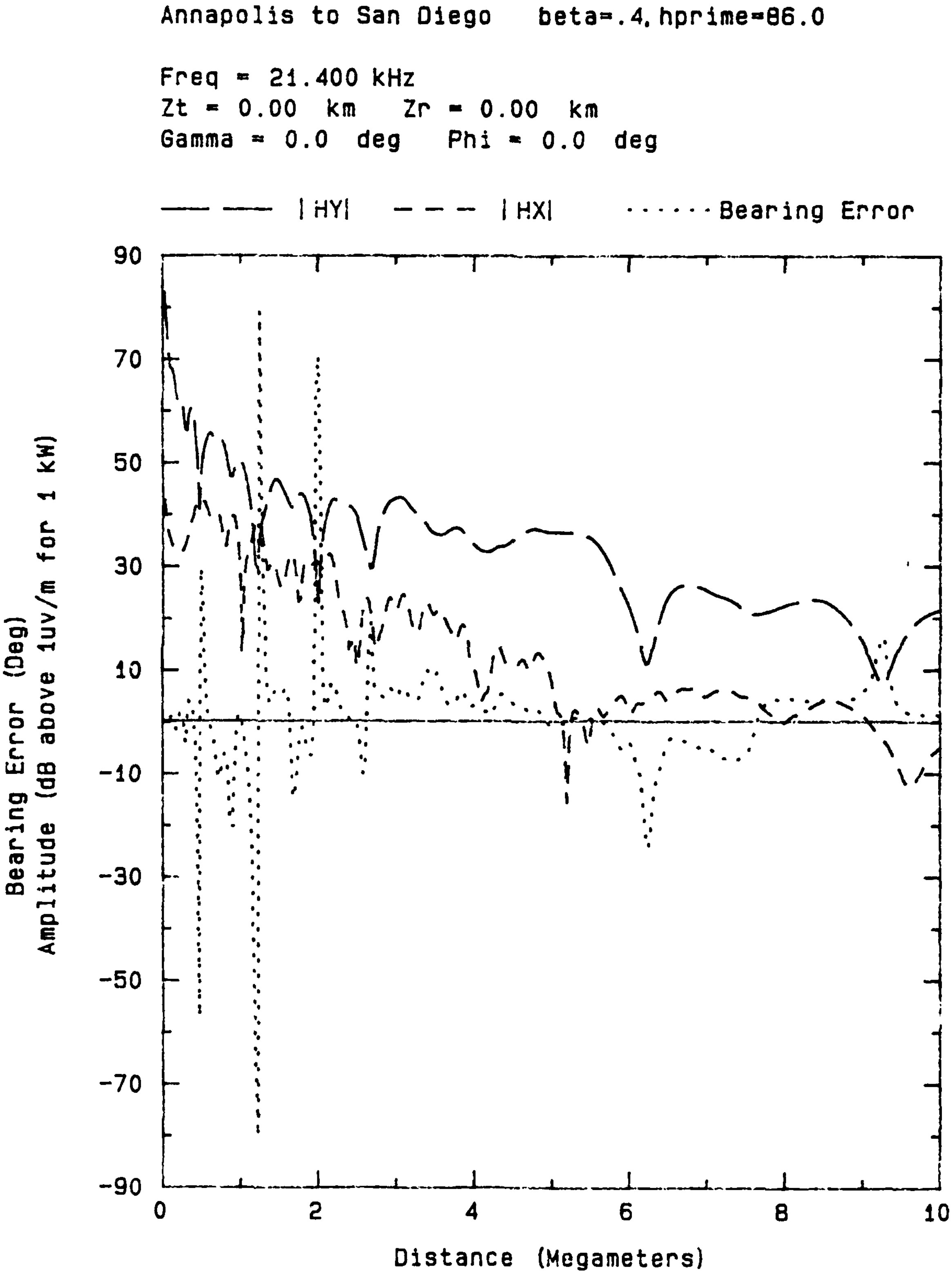


Figure 9. Sample range plot for Annapolis to San Diego - Night.

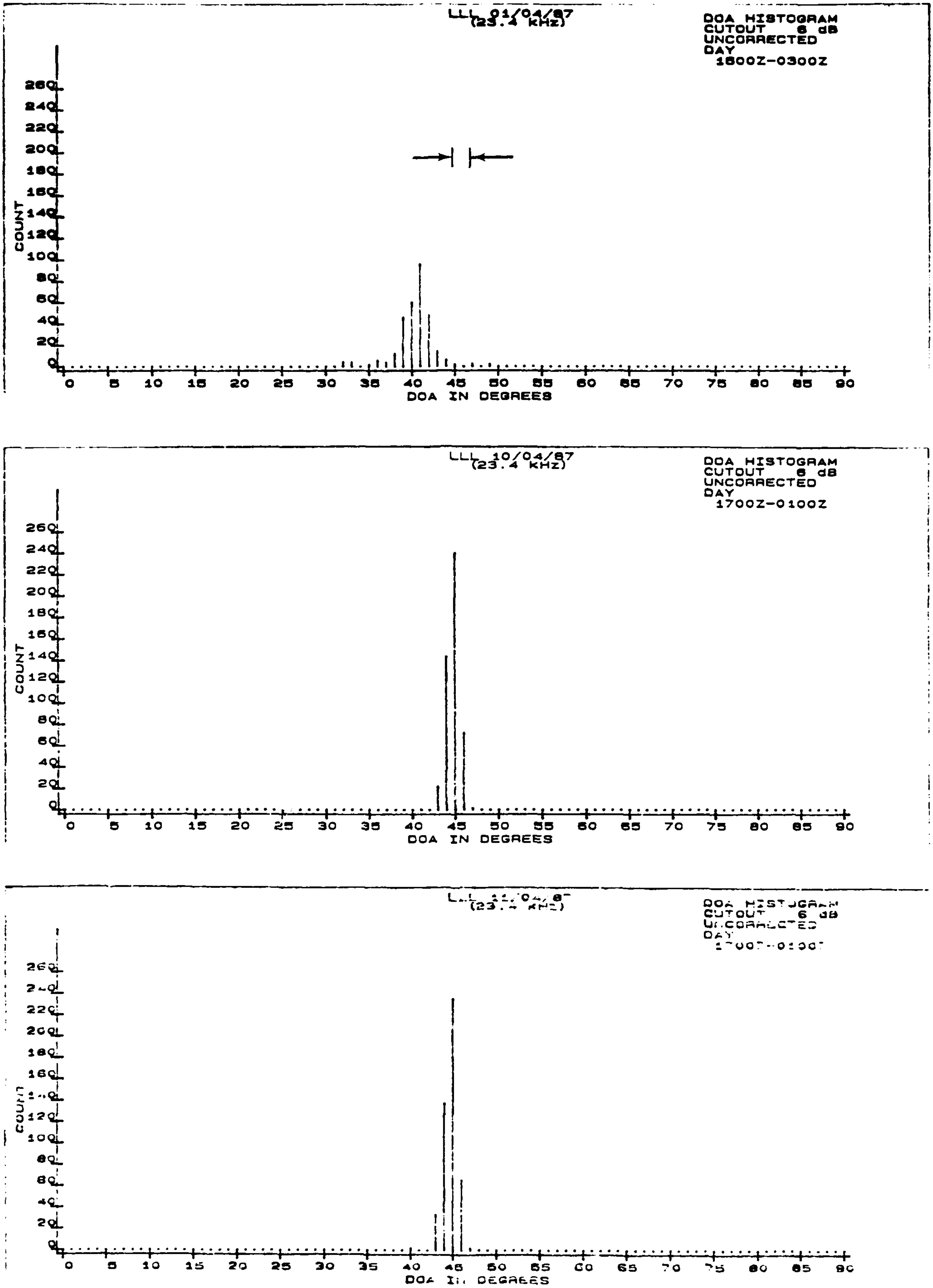


Figure 10. Histograms for Lualualei to San Diego - Day.

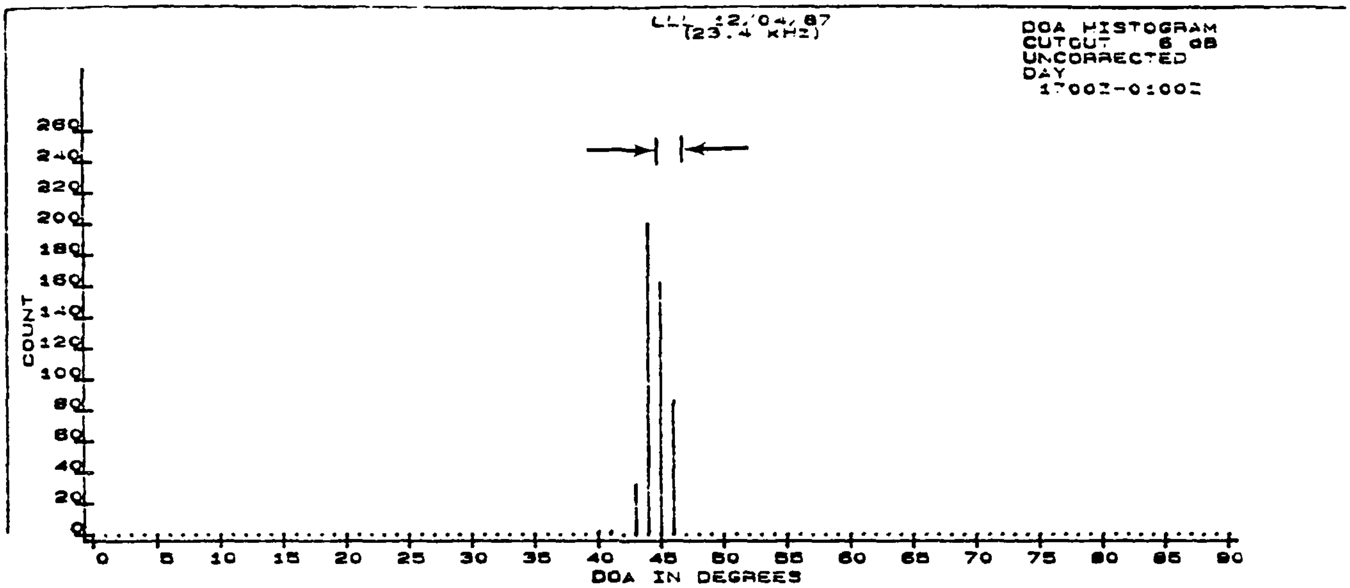


Figure 11. Histograms for Lualualei to San Diego - Day.

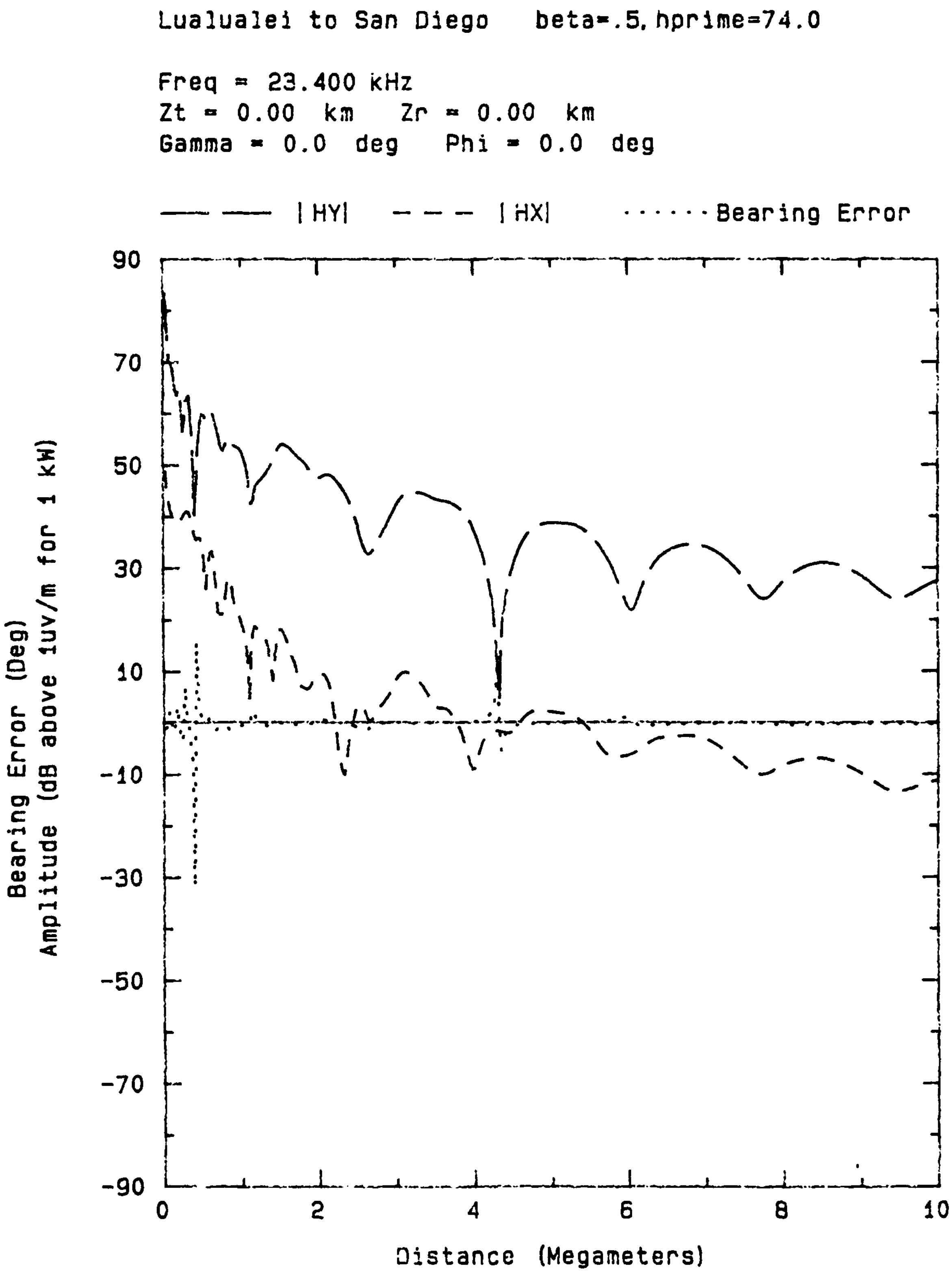
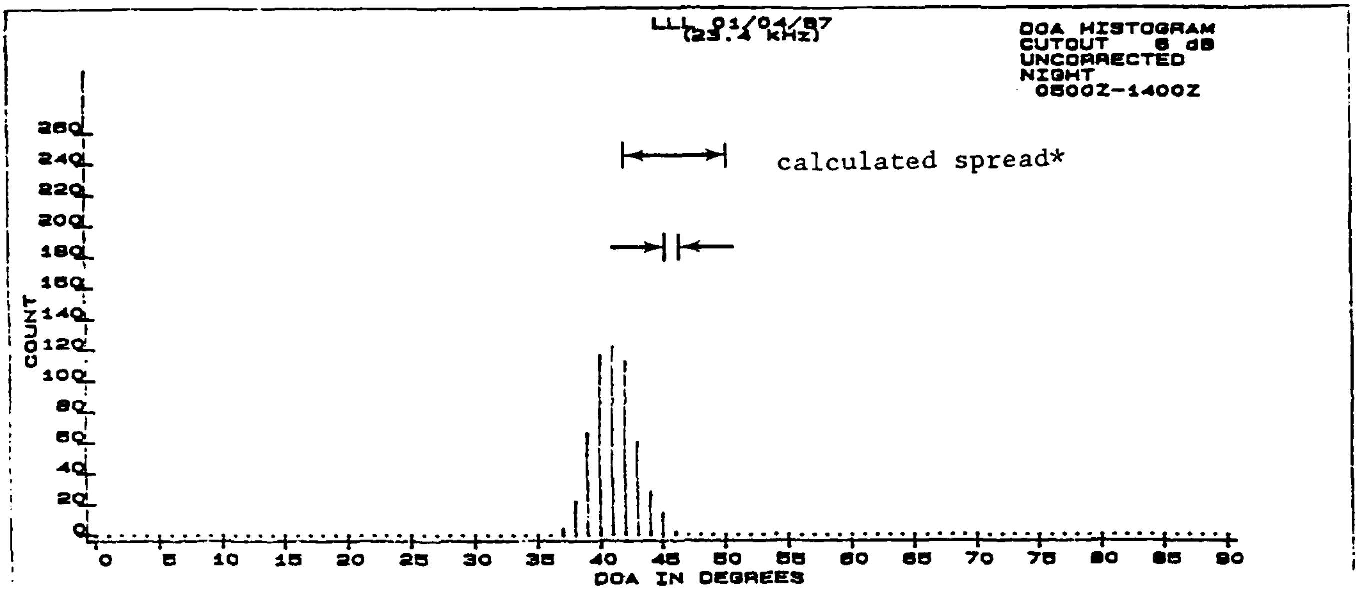
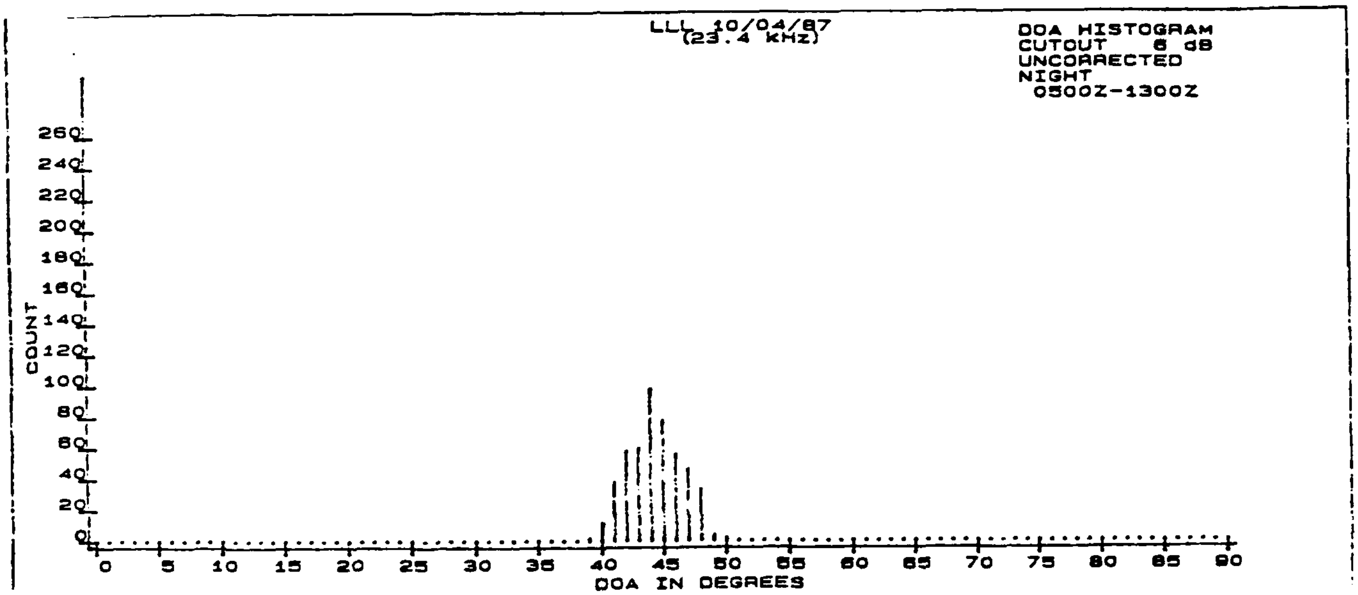


Figure 12. Sample range plot for Lualualei to San Diego - Day.





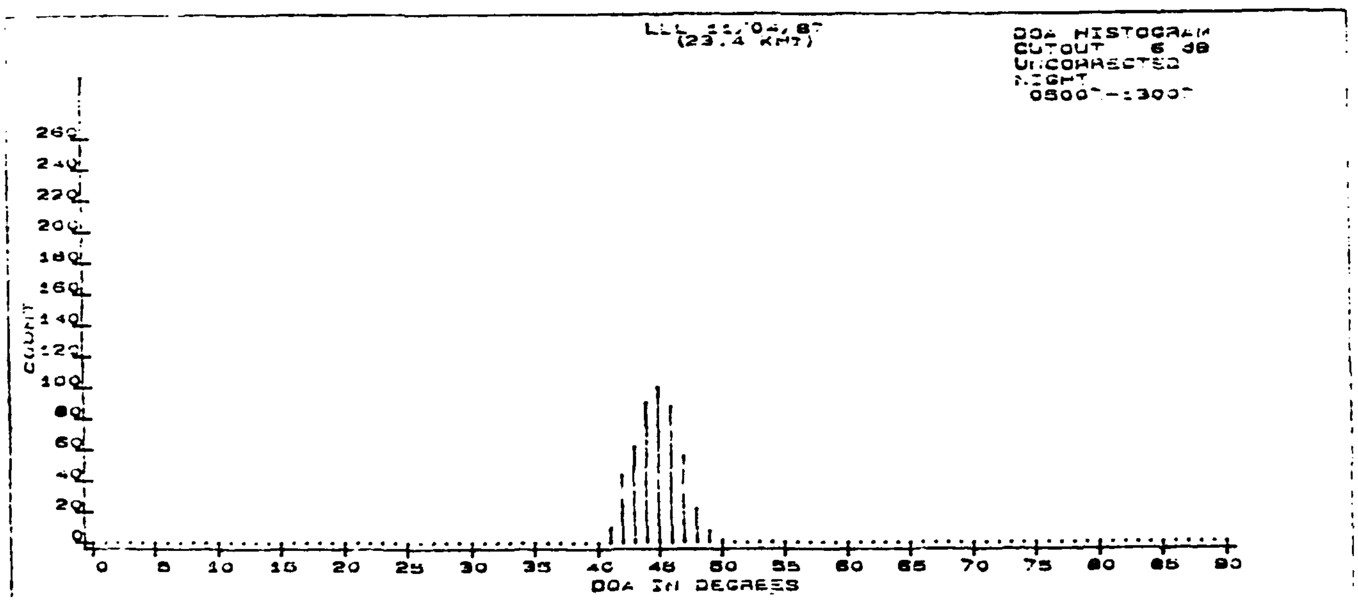


Figure 13. Histograms for Lualualei to San Diego - Night.

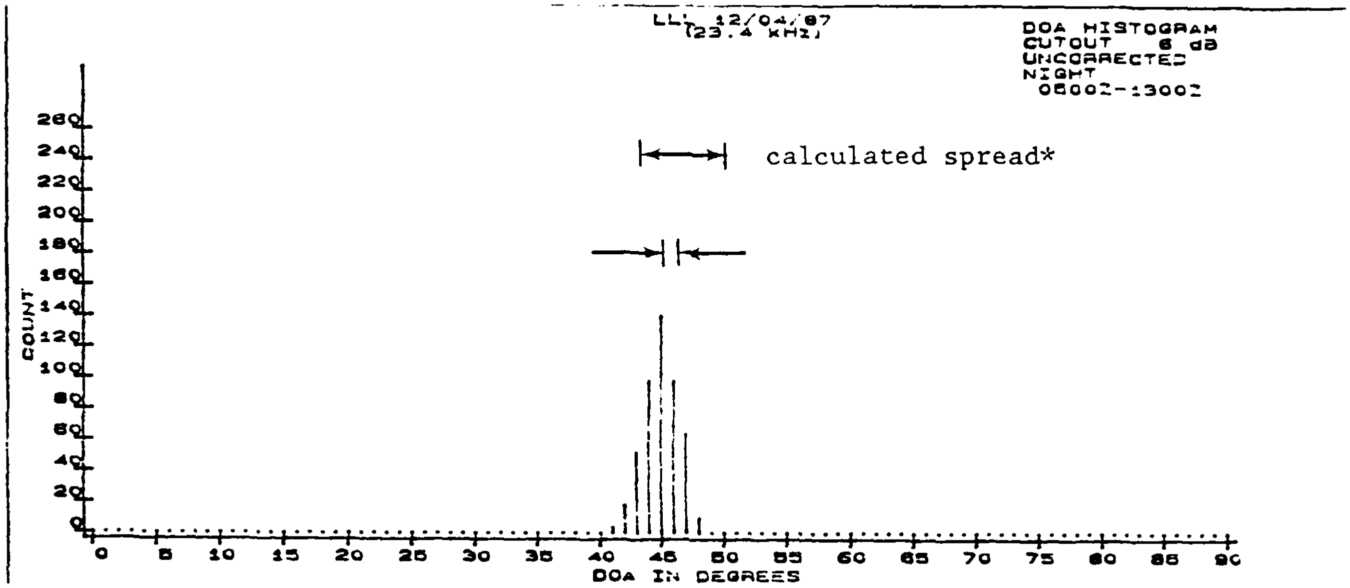


Figure 14. Histograms for Lualualei to San Diego - Night.

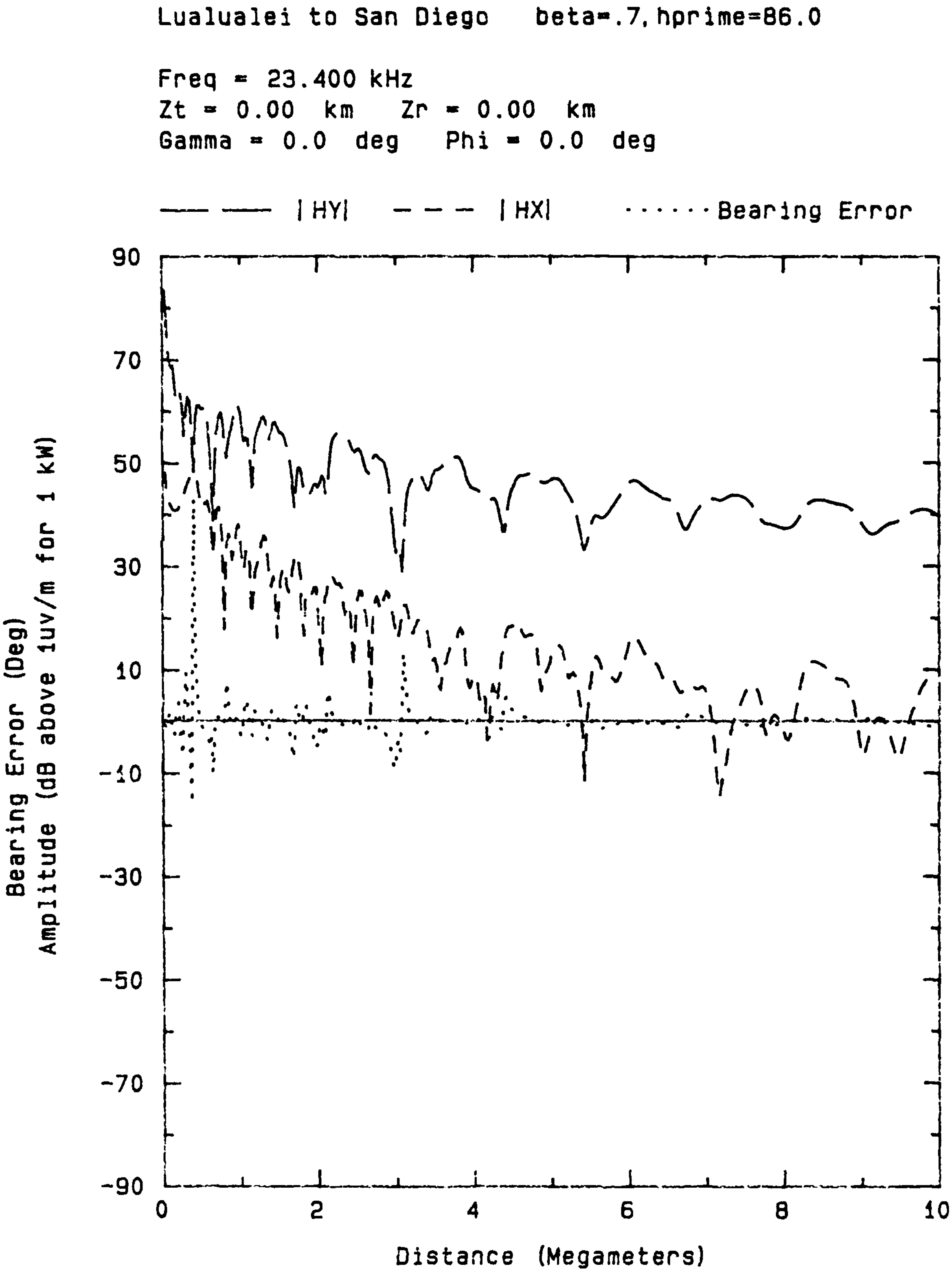


Figure 15. Sample range plot for Lualualei to San Diego - Night.

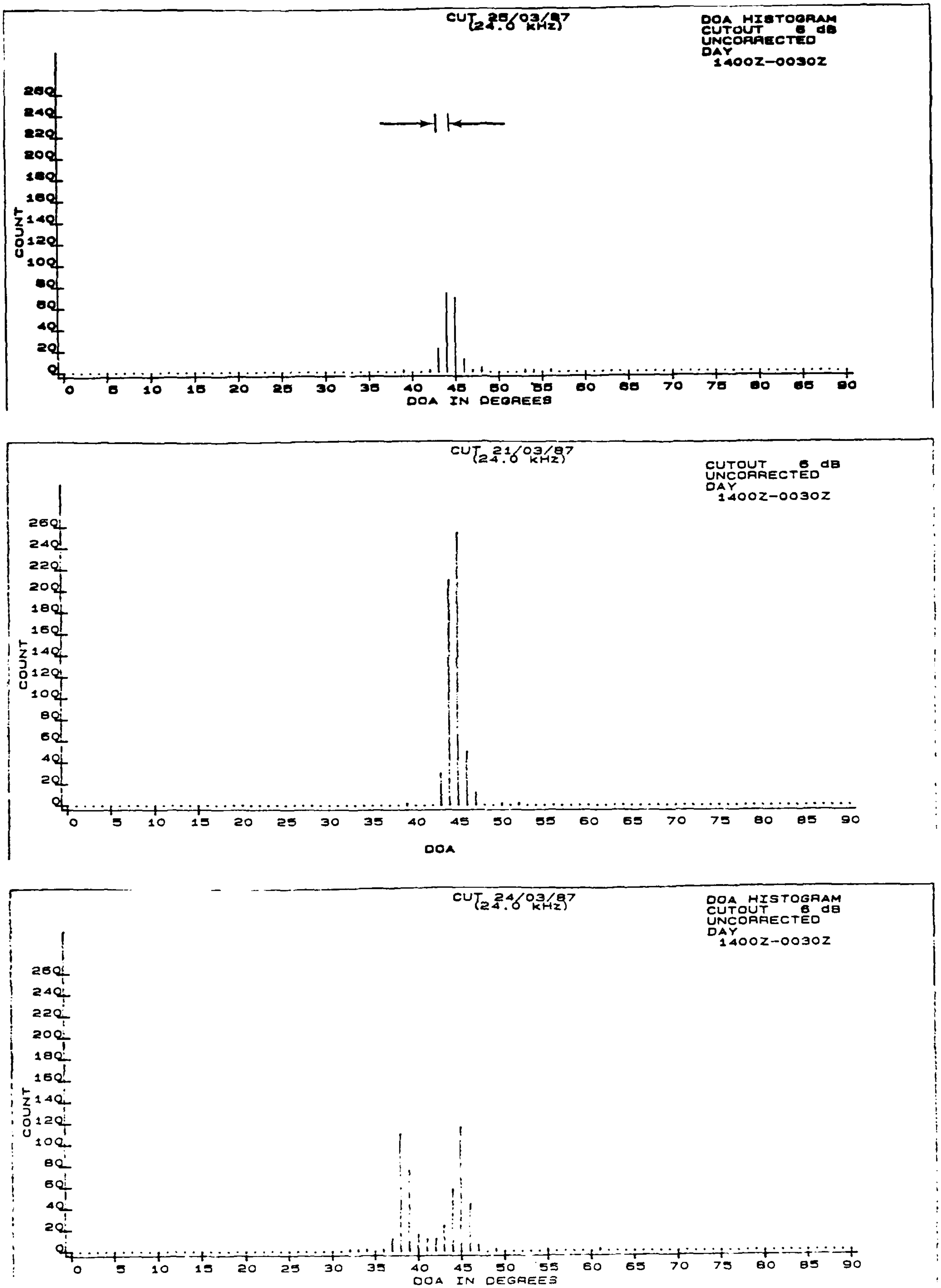


Figure 16. Histograms for Cutler to San Diego - Day.

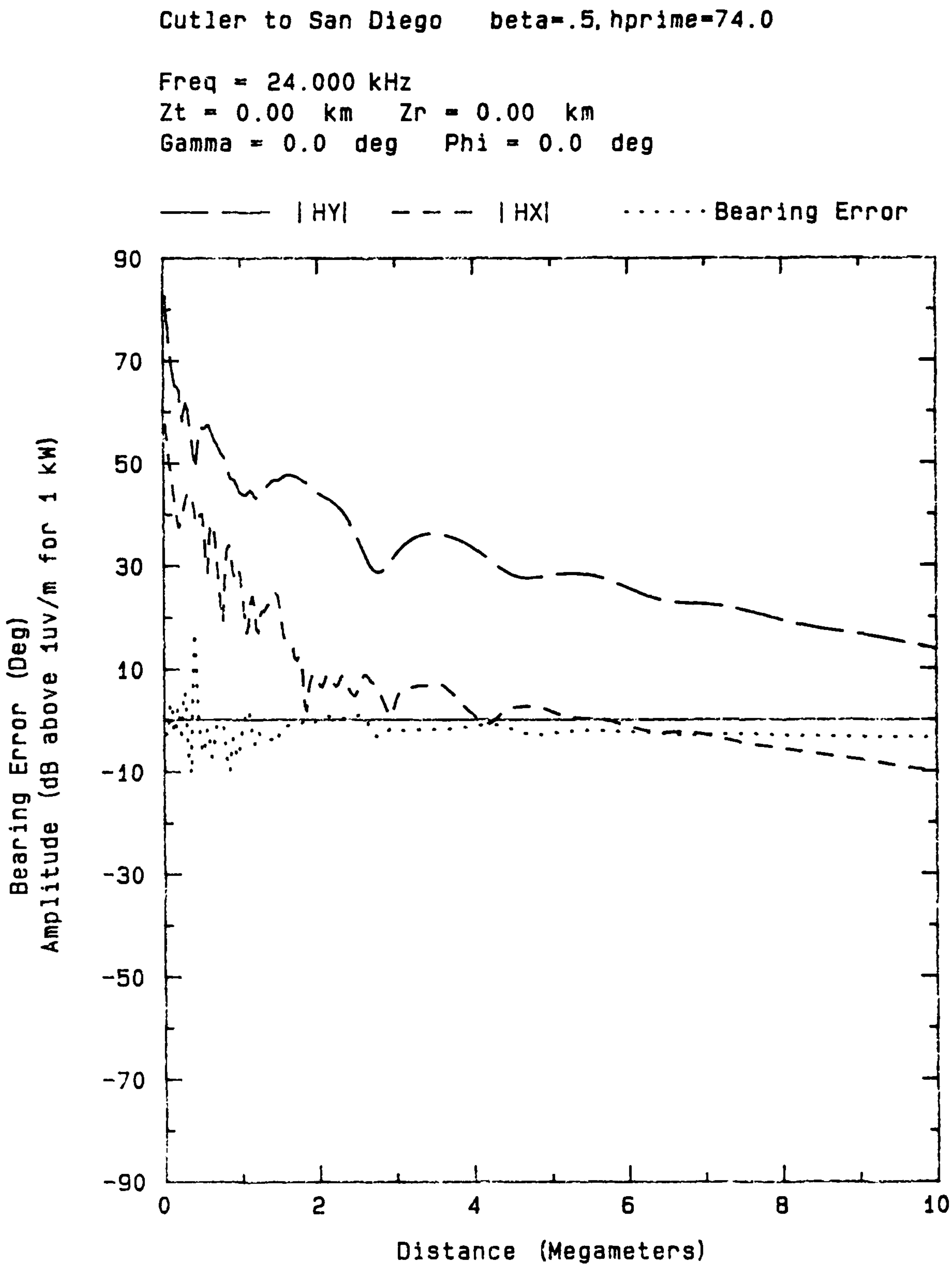


Figure 17. Sample range plot for Cutler to San Diego - Day.

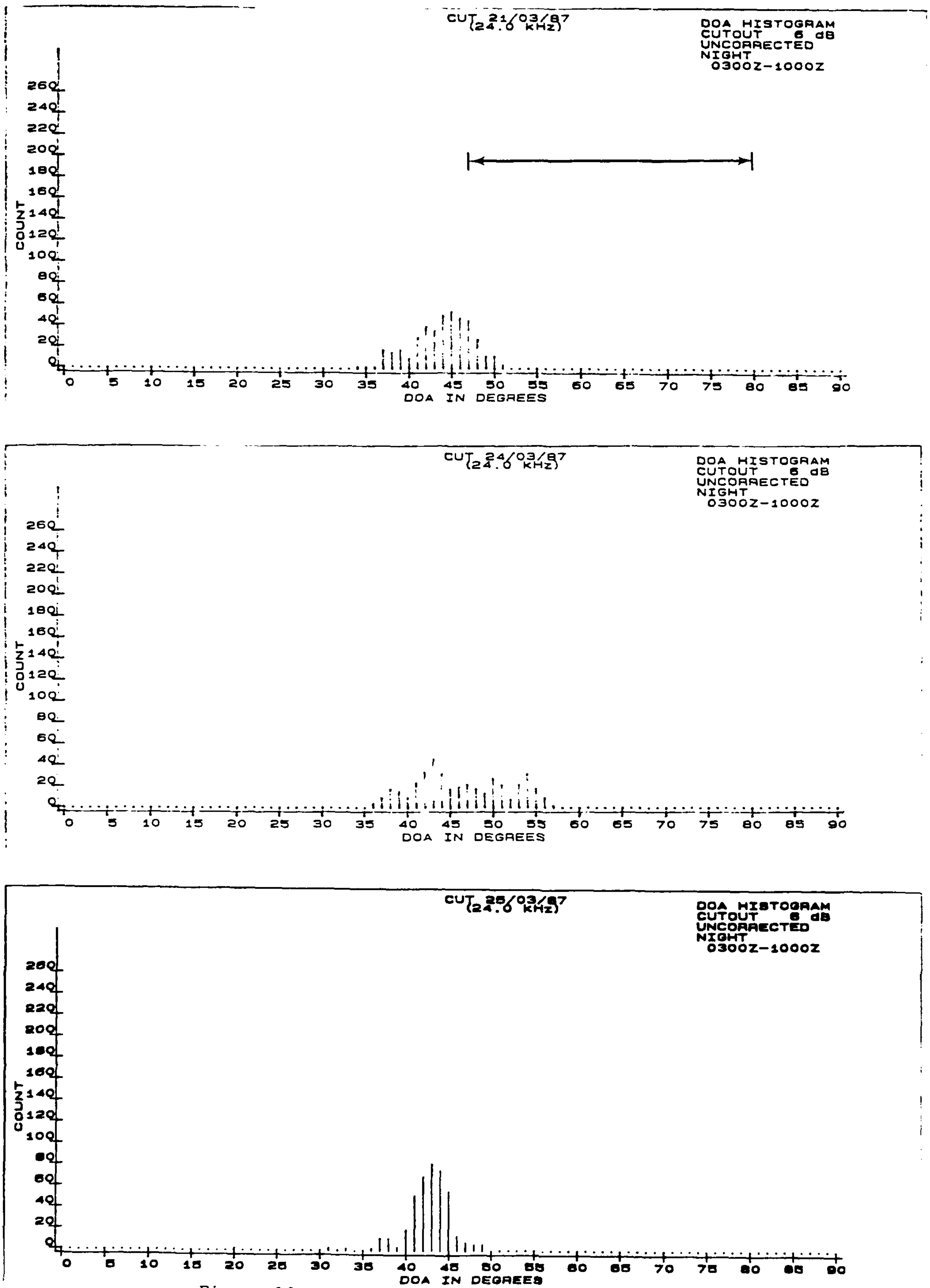


Figure 18. Histograms for Cutler to San Diego - Night.

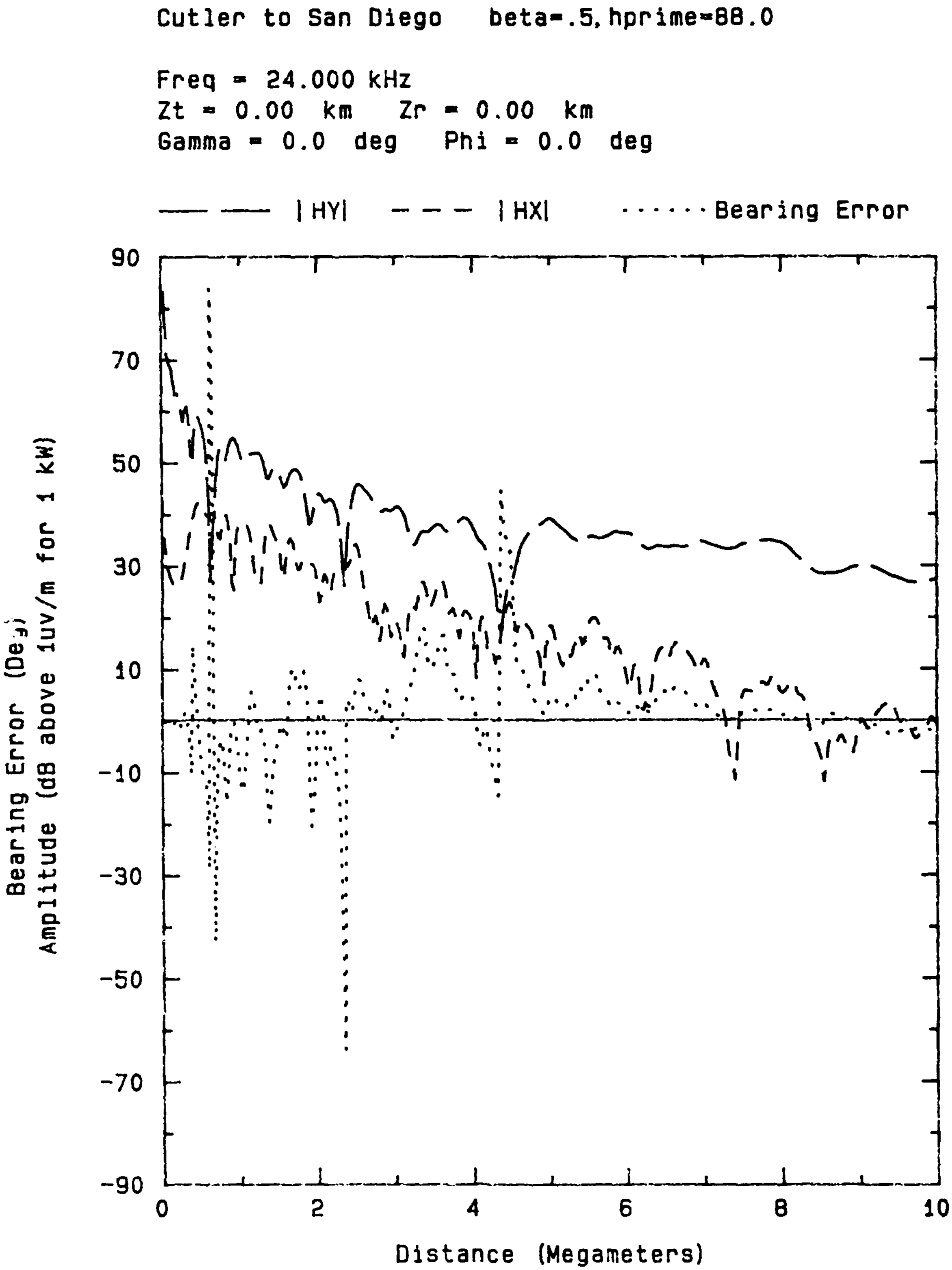


Figure 19. Sample range plot for Cutler to San Diego - Night.

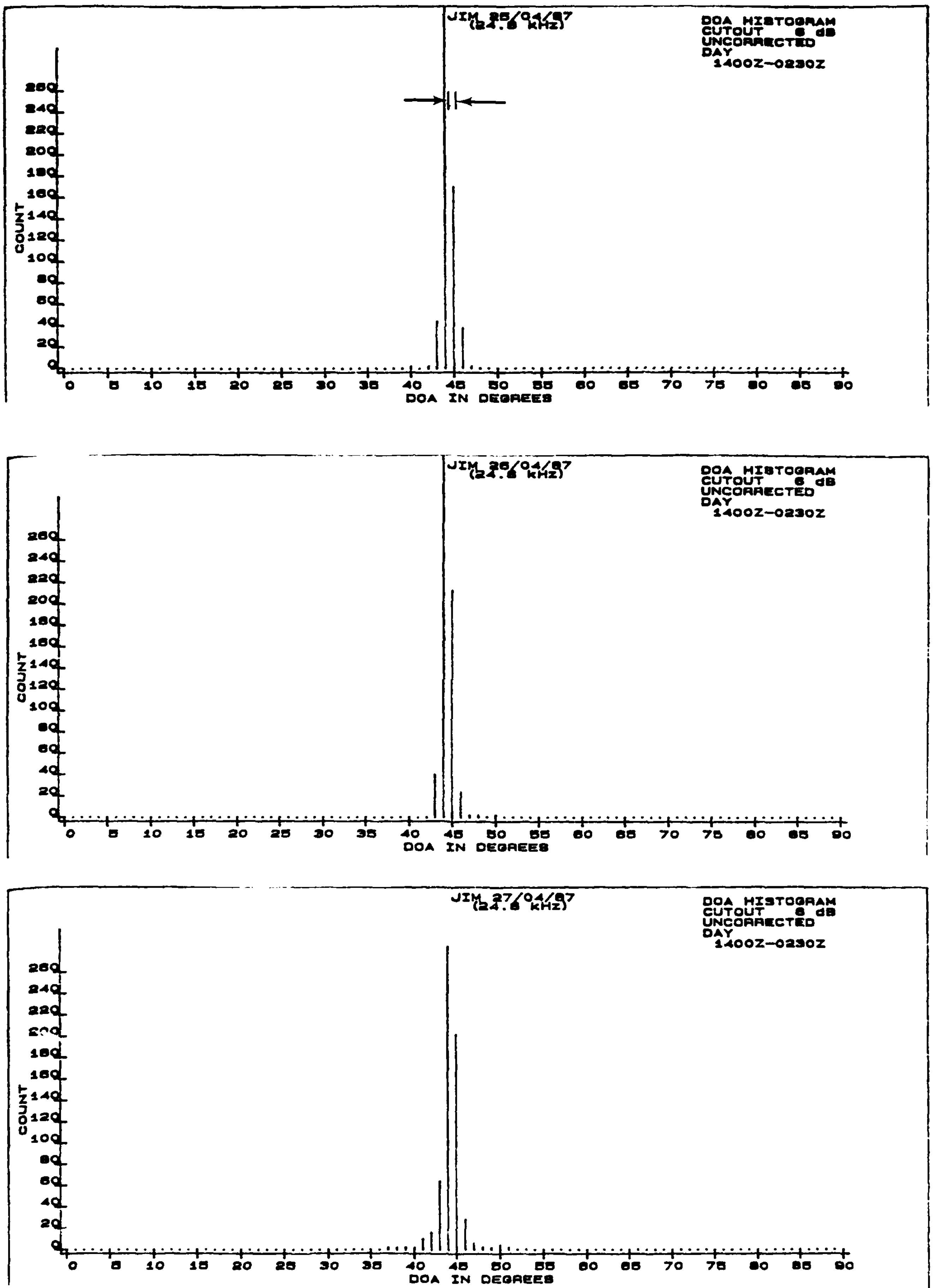


Figure 20. Histograms for Jim Creek to San Diego - Day.

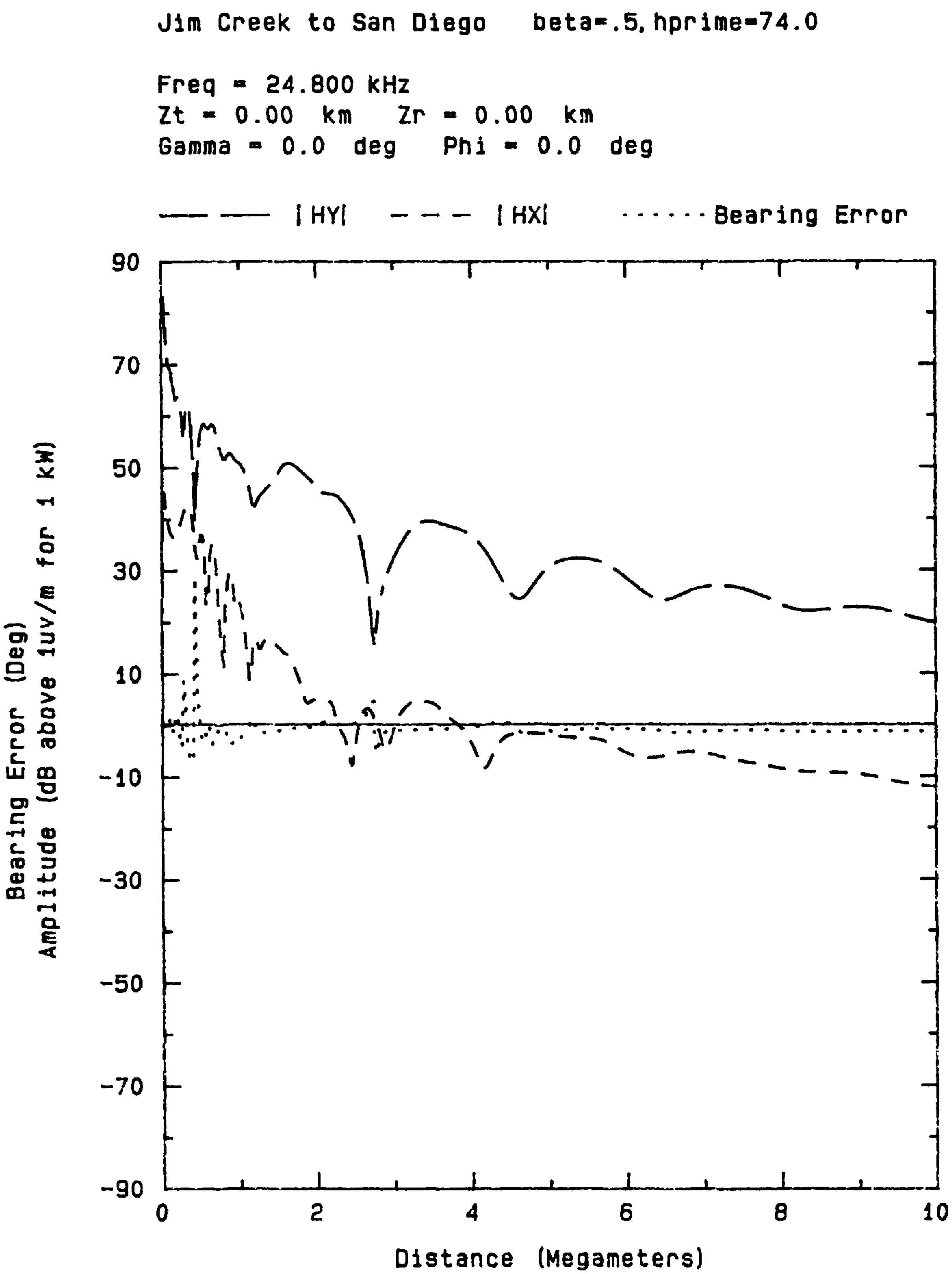
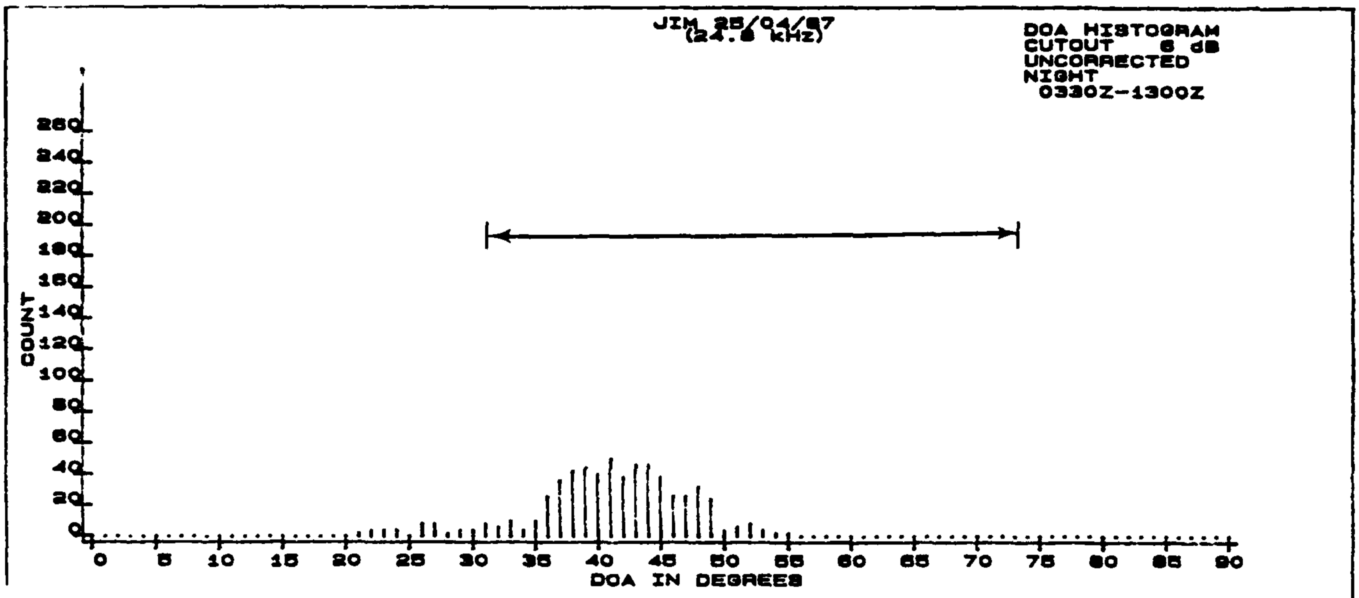
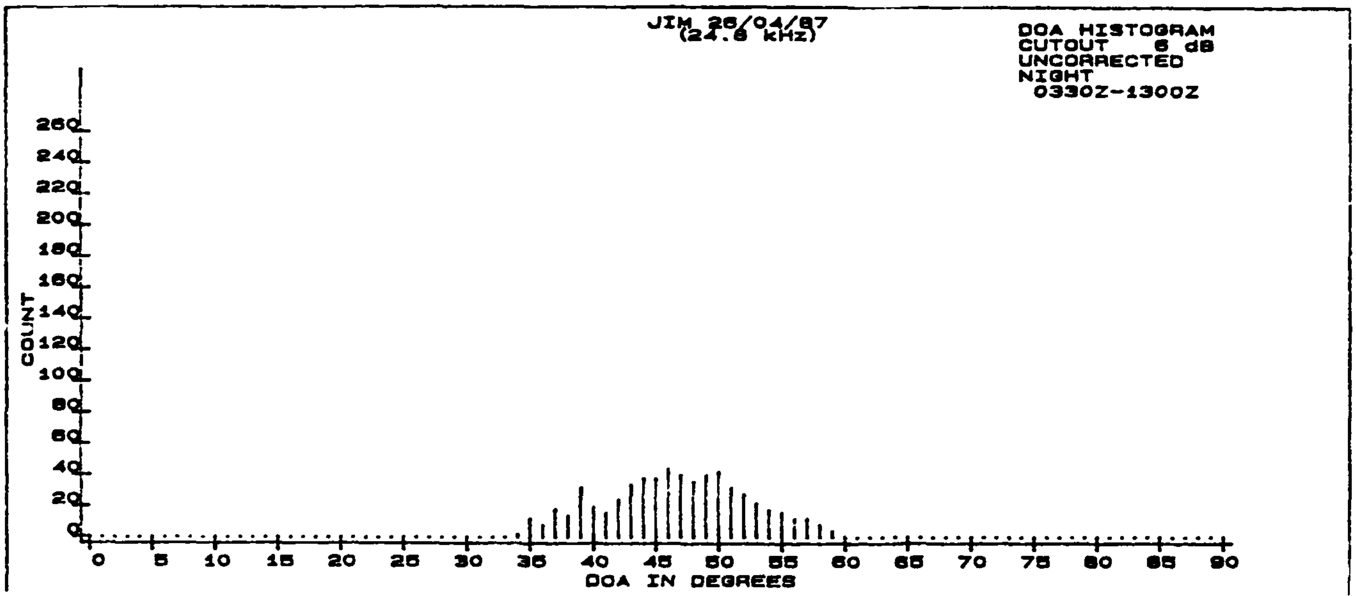


Figure 21. Sample range plot for Jim Creek to San Diego - Day.





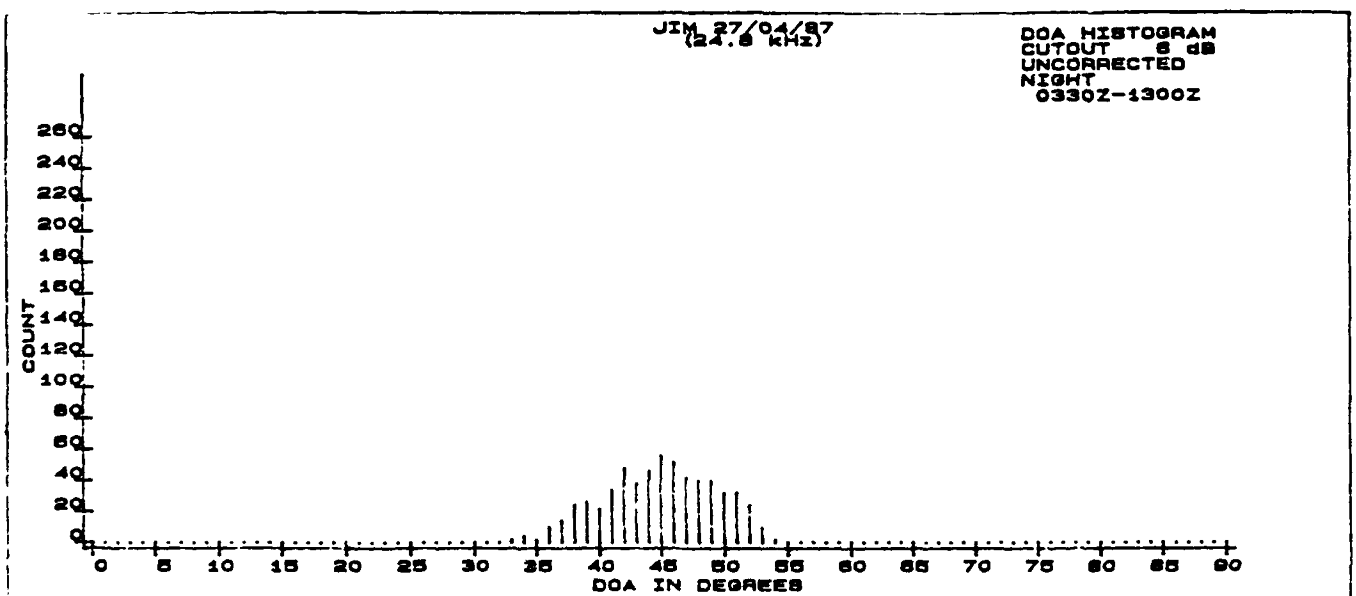
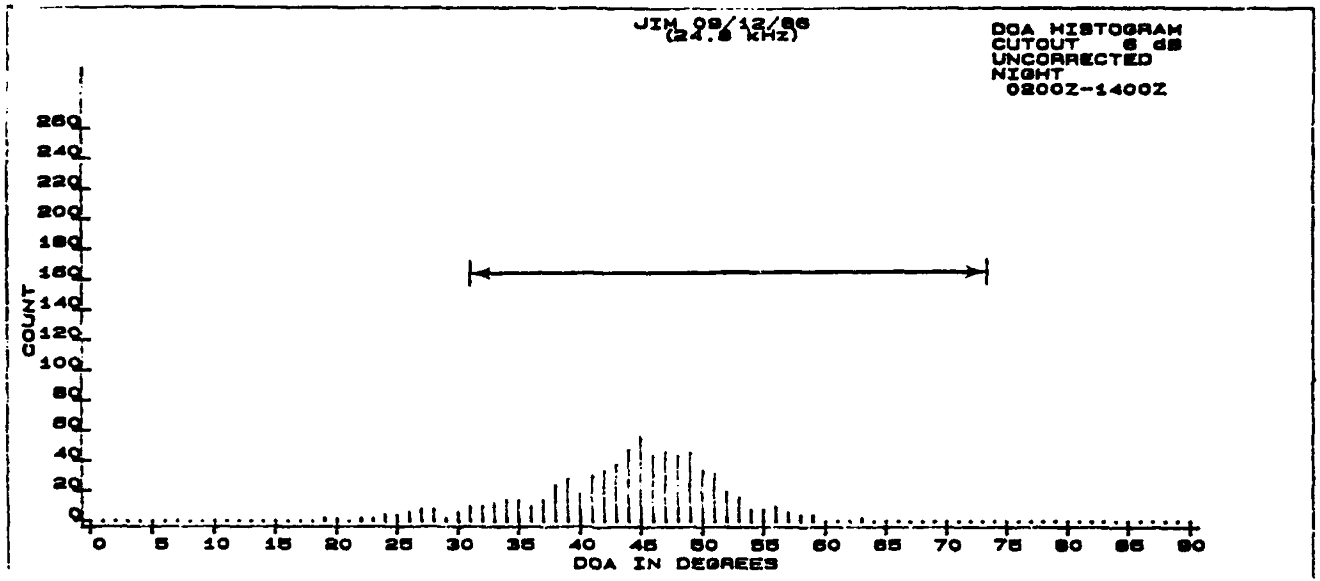
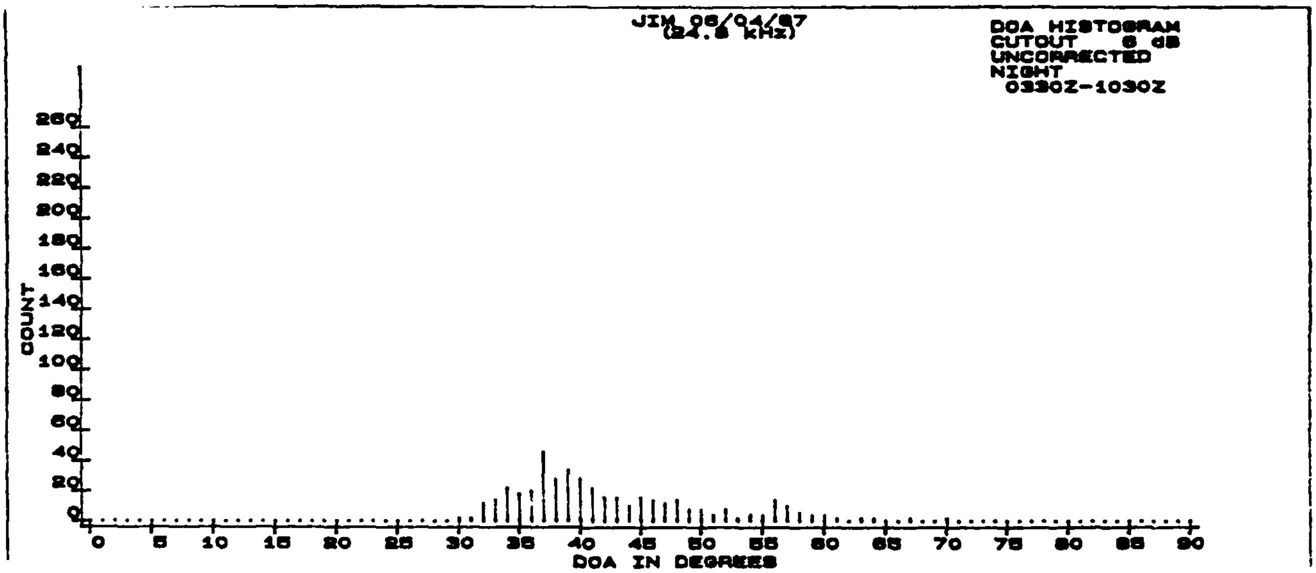


Figure 22. Histograms for Jim Creek to San Diego - Night.





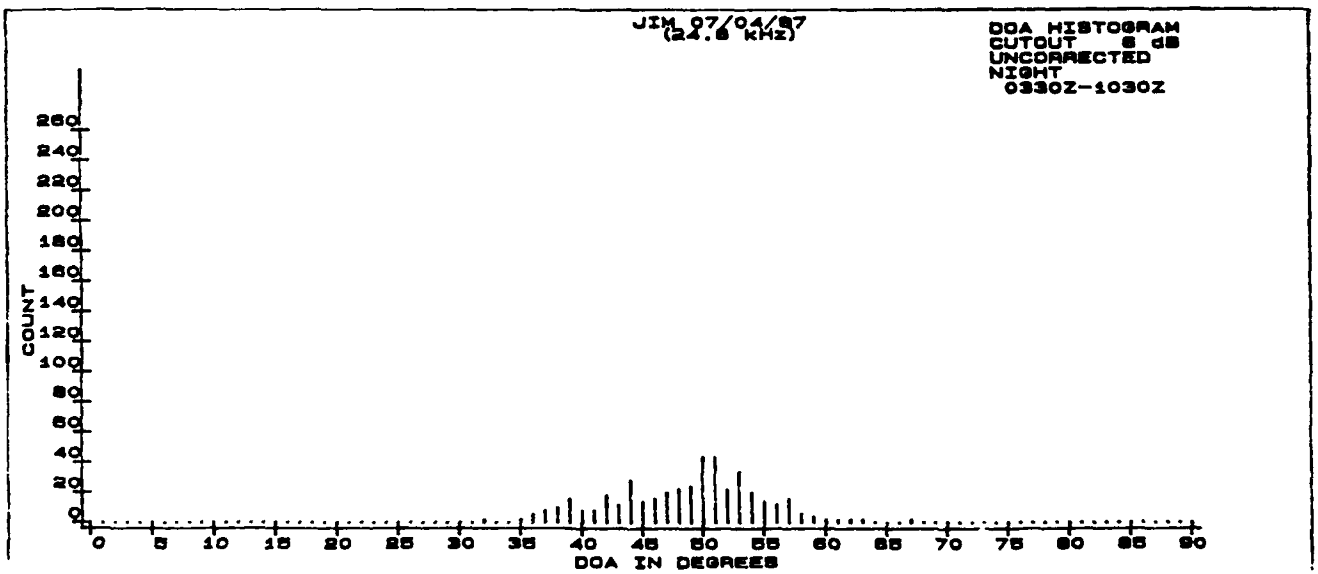


Figure 23. Histograms for Jim Creek to San Diego - Night.

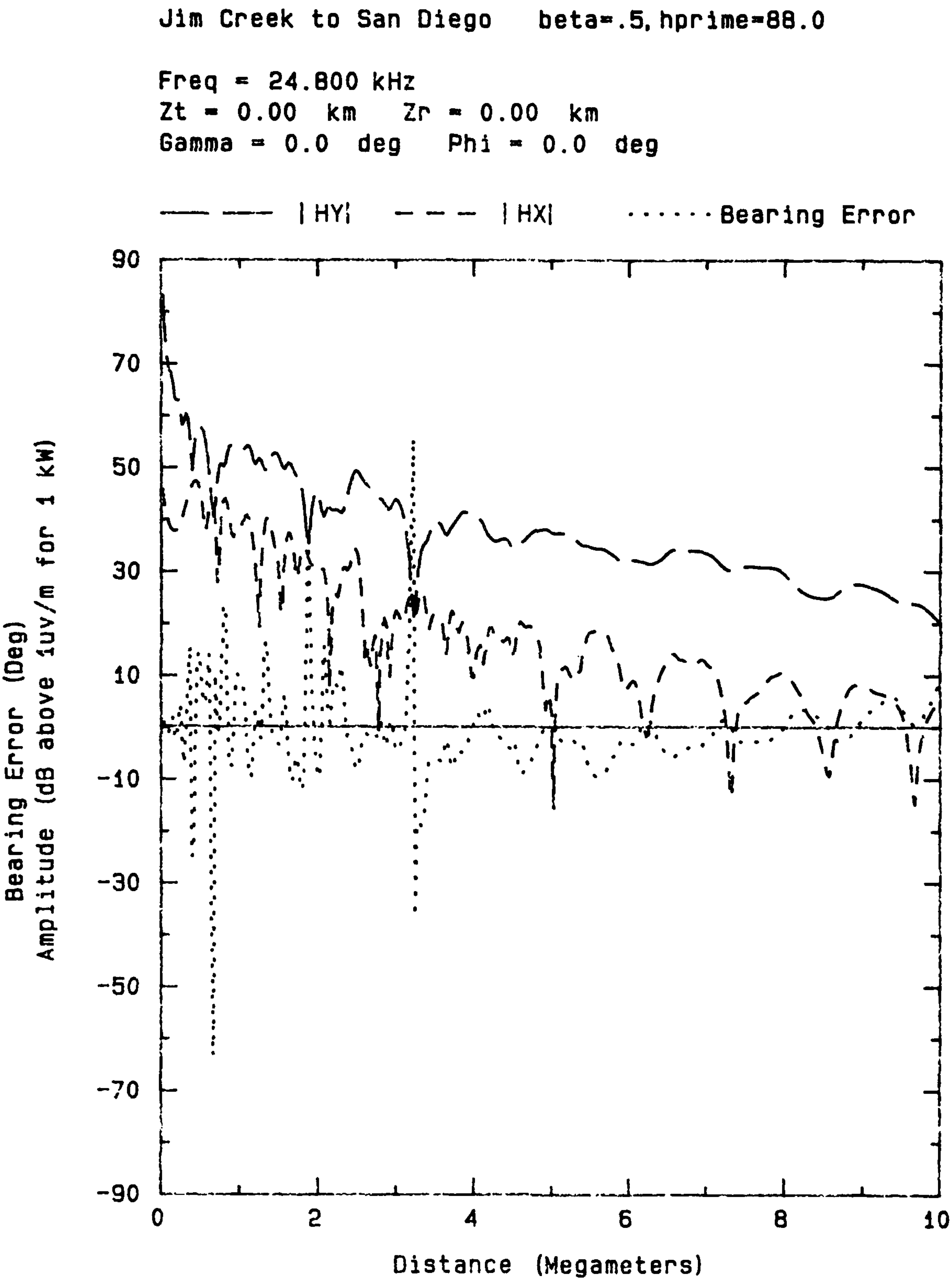
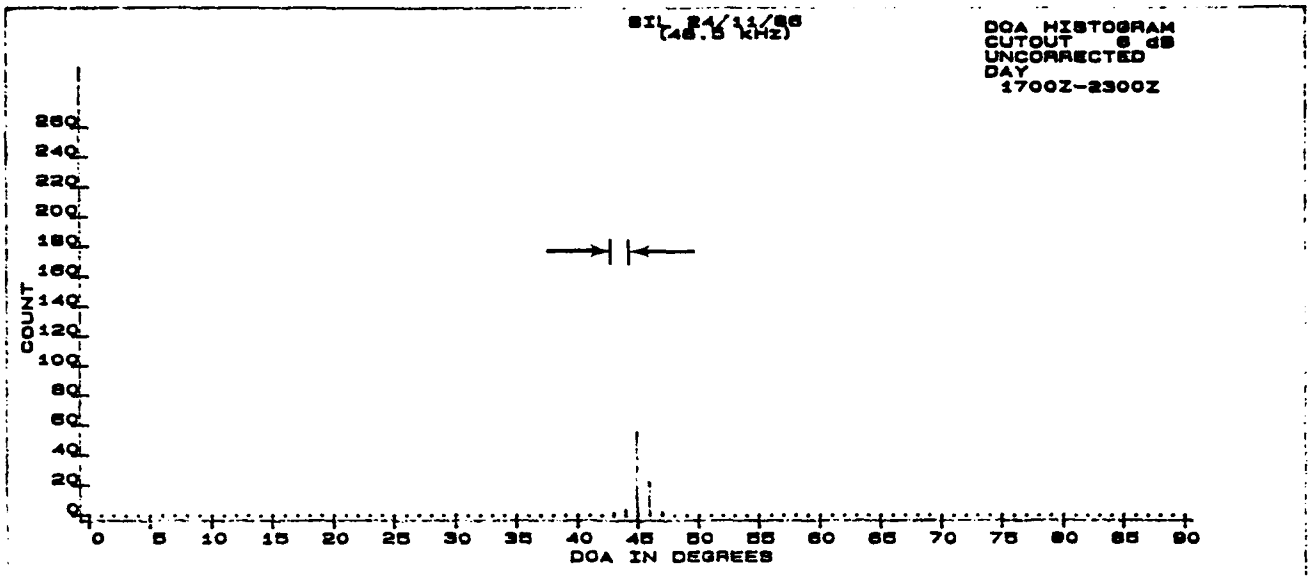
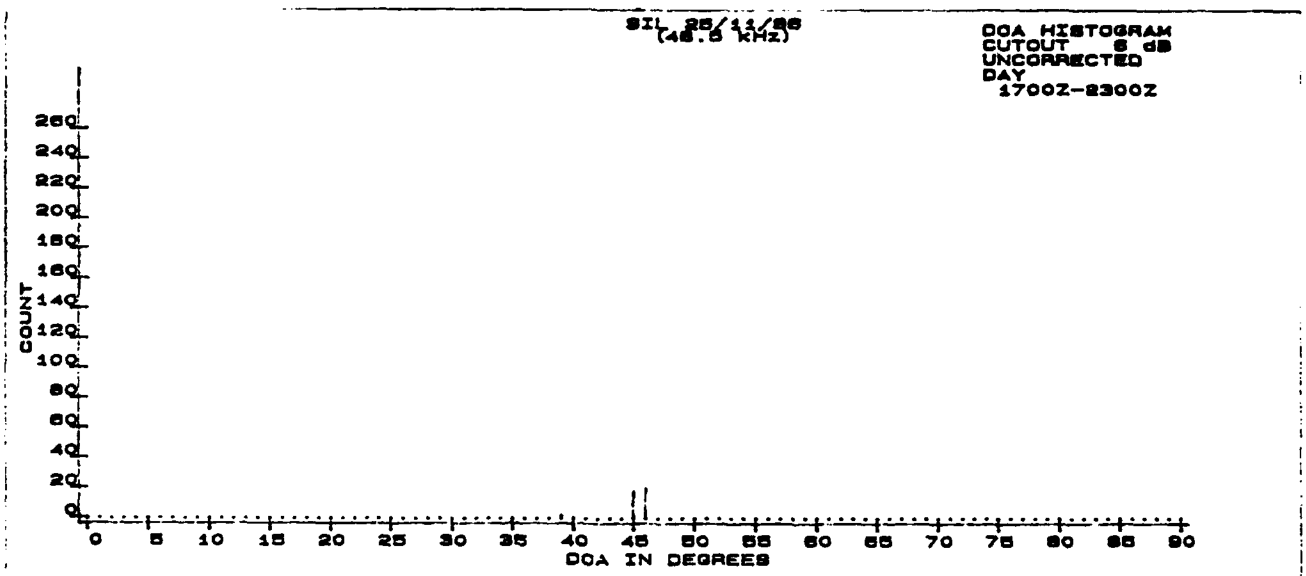


Figure 24. Sample range plot for Jim Creek to San Diego - Night.





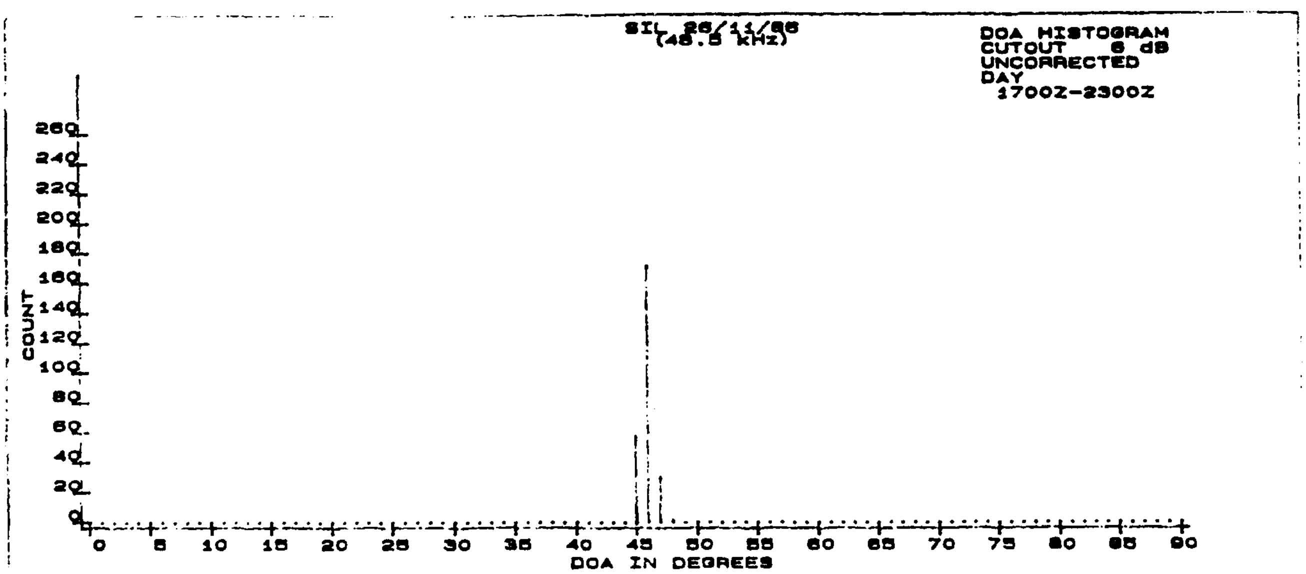
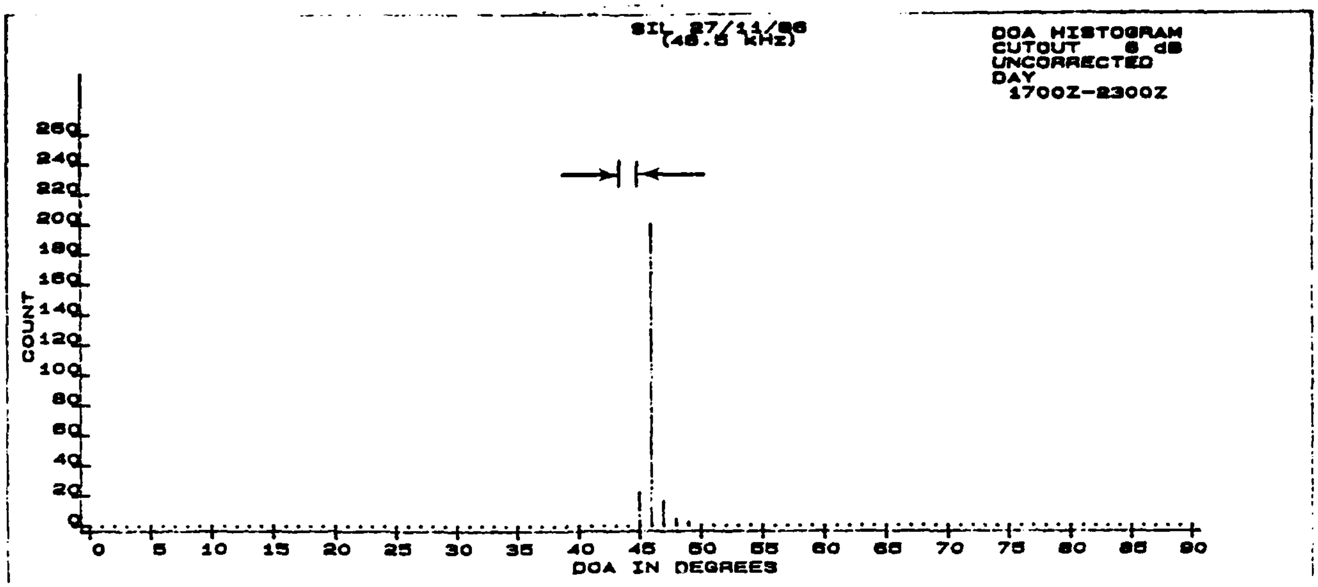
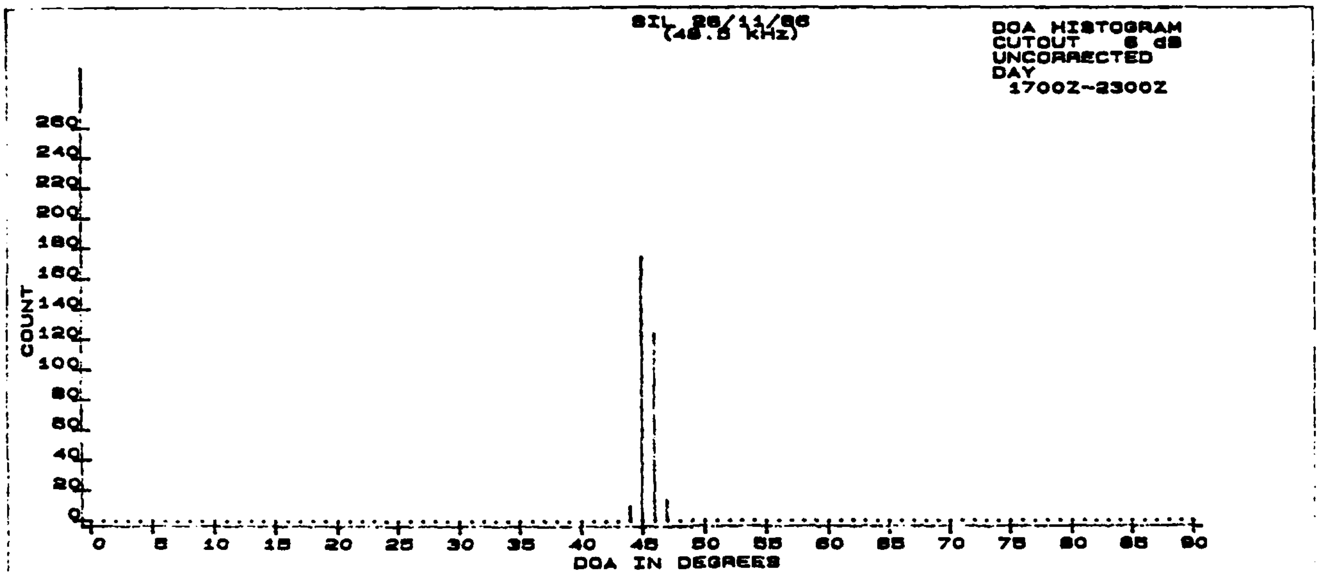


Figure 25. Histograms for Silver Creek to San Diego - Day.





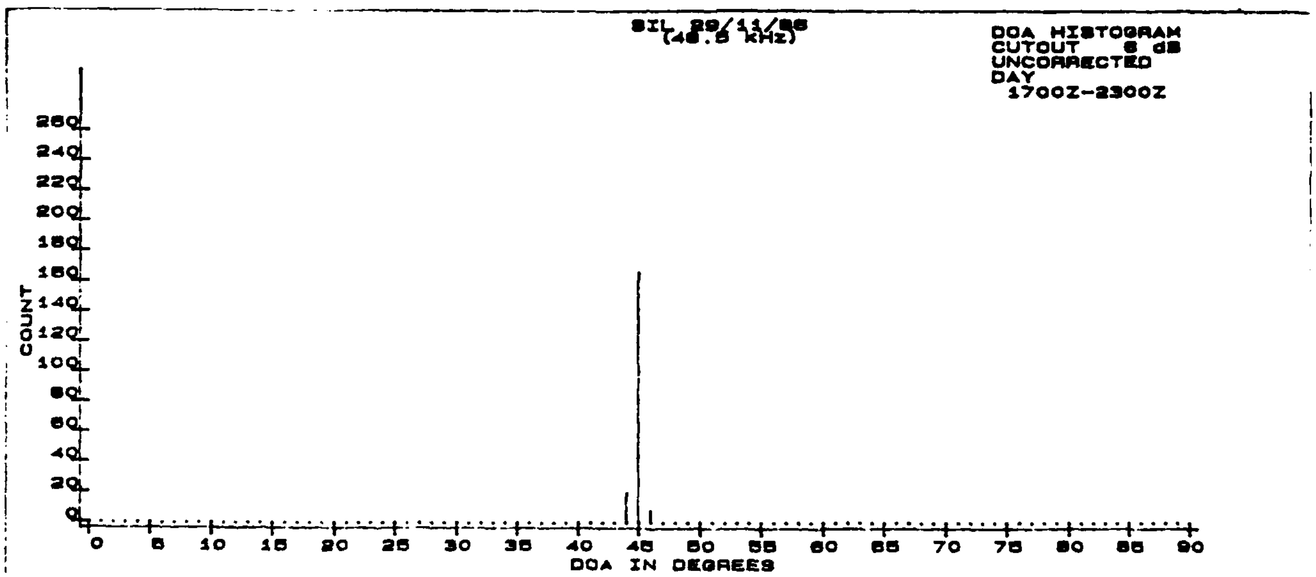
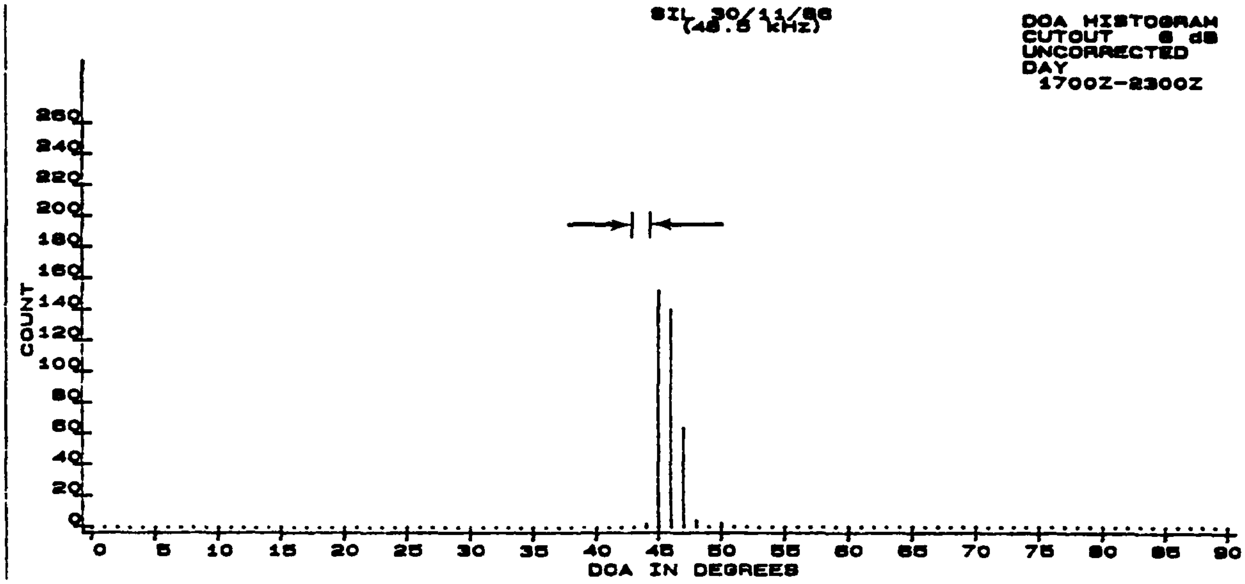


Figure 26. Histograms for Silver Creek to San Diego - Day.



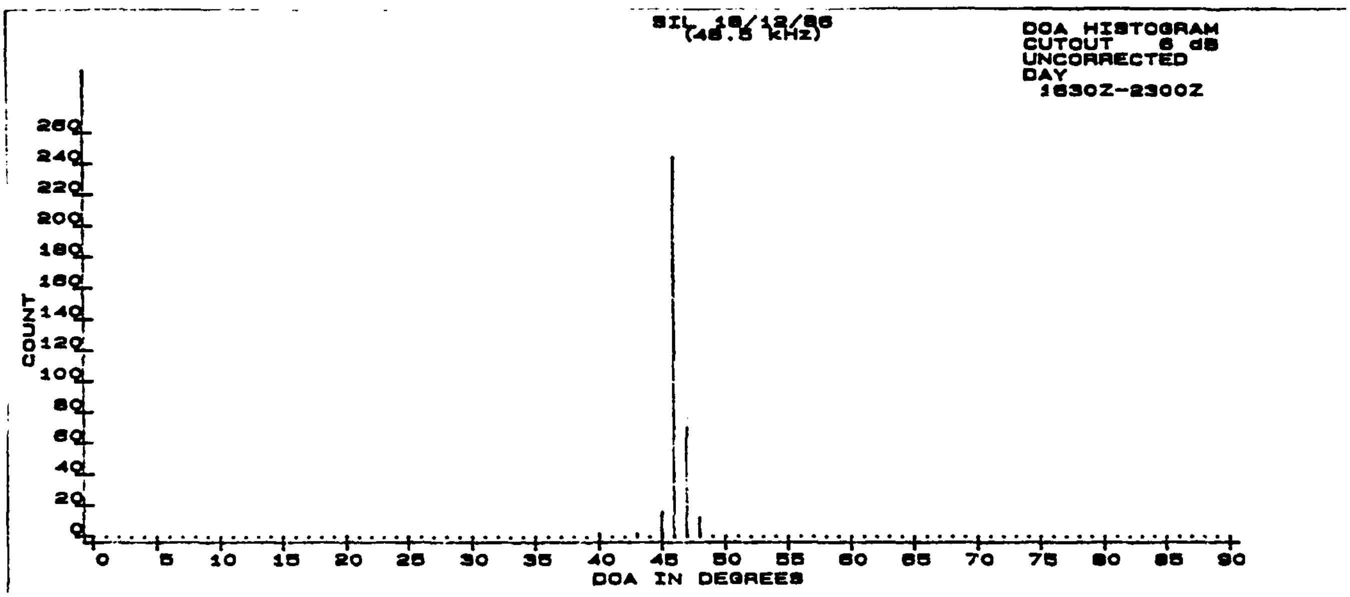


Figure 27. Histograms for Silver Creek to San Diego - Day.

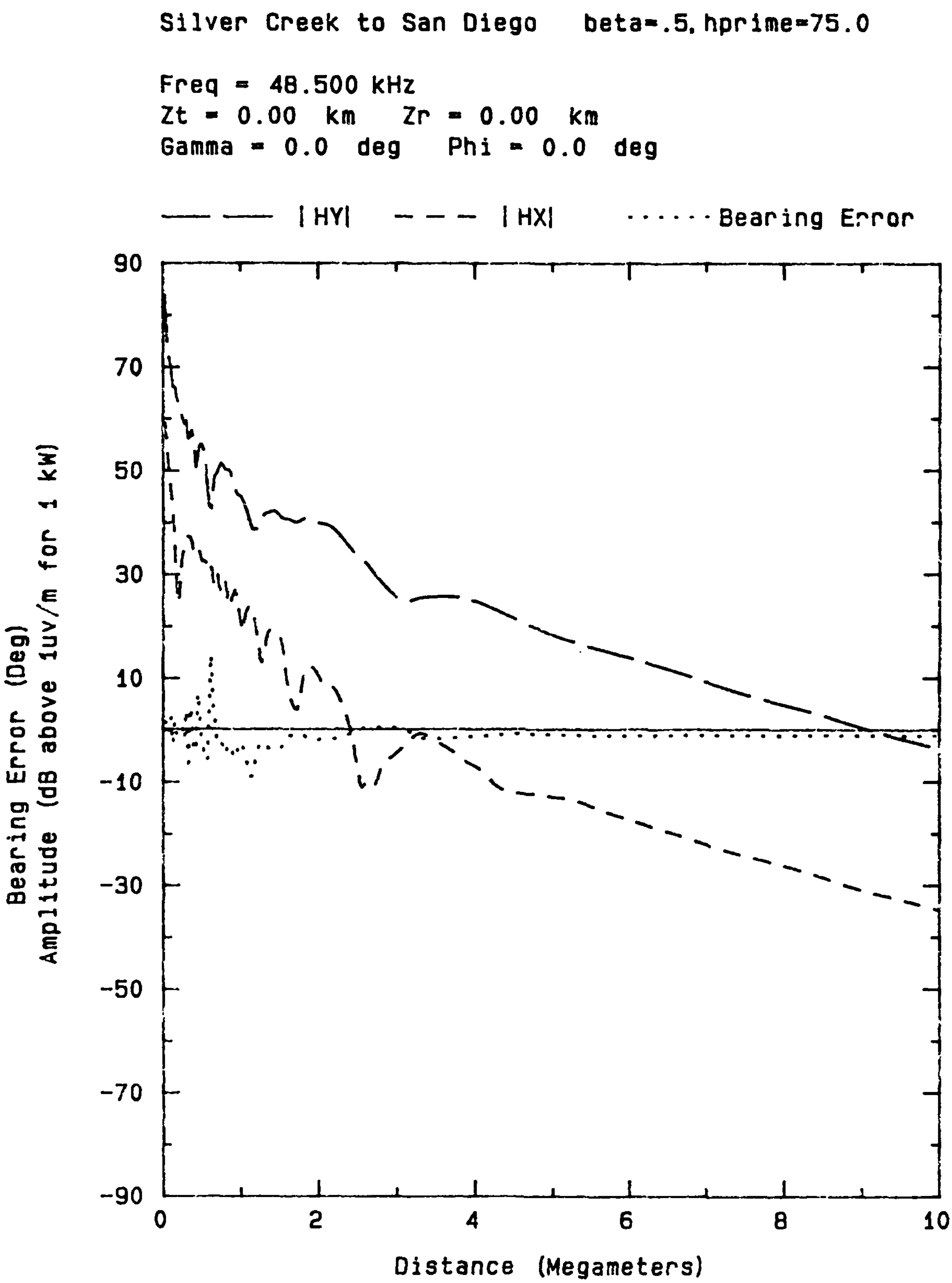
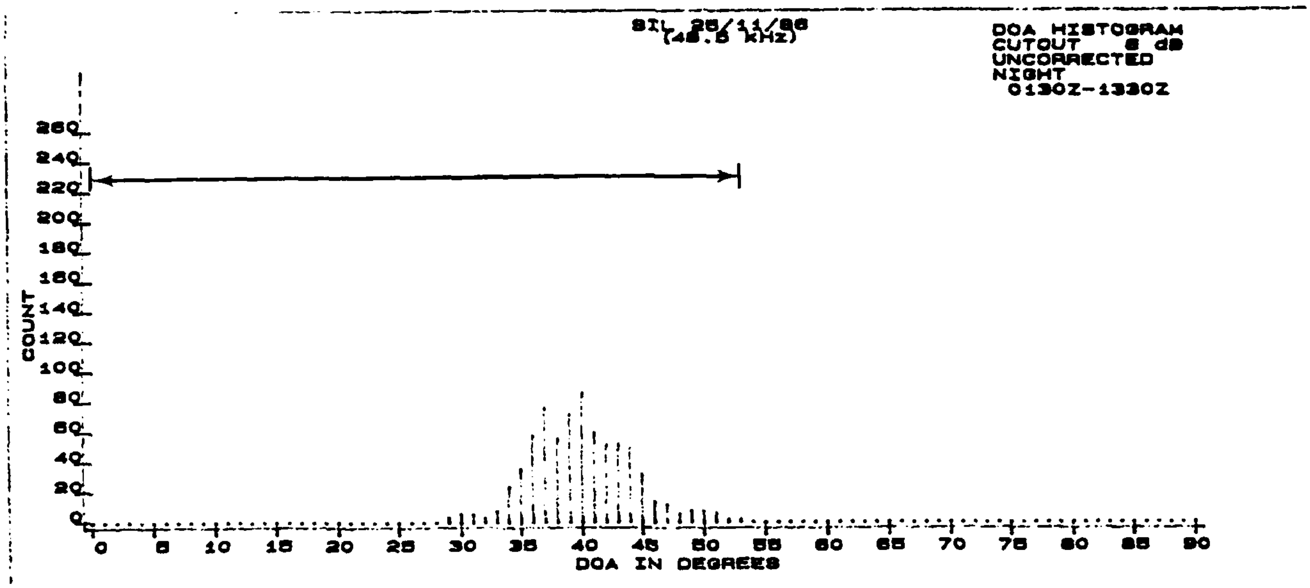
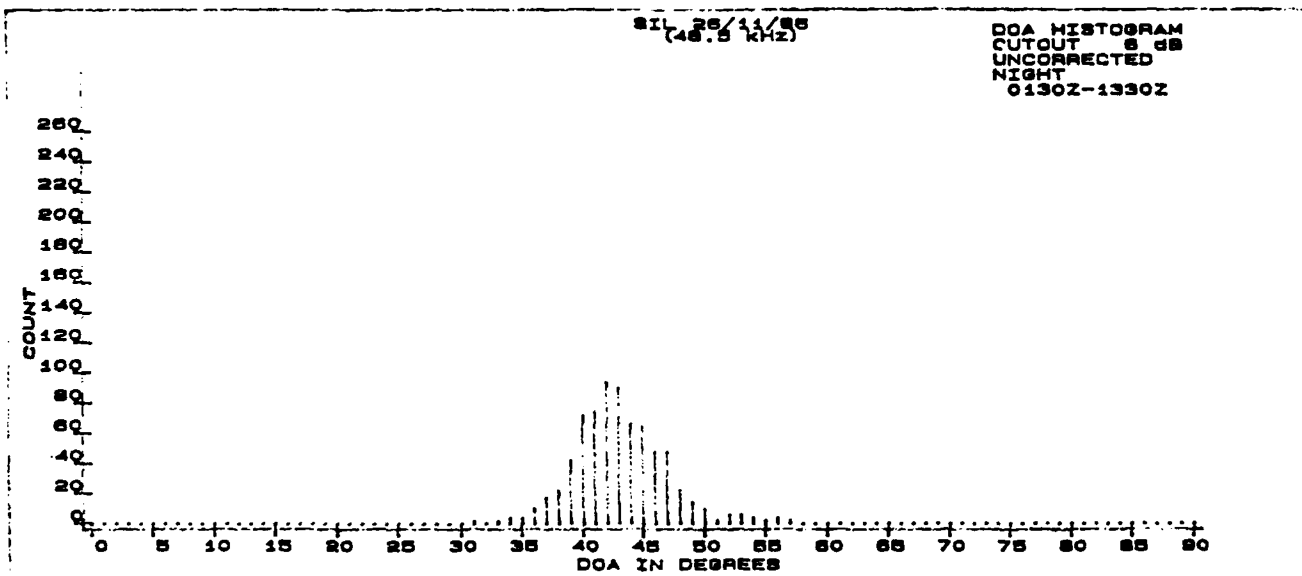


Figure 28. Sample range plot for Silver Creek to San Diego - Day.





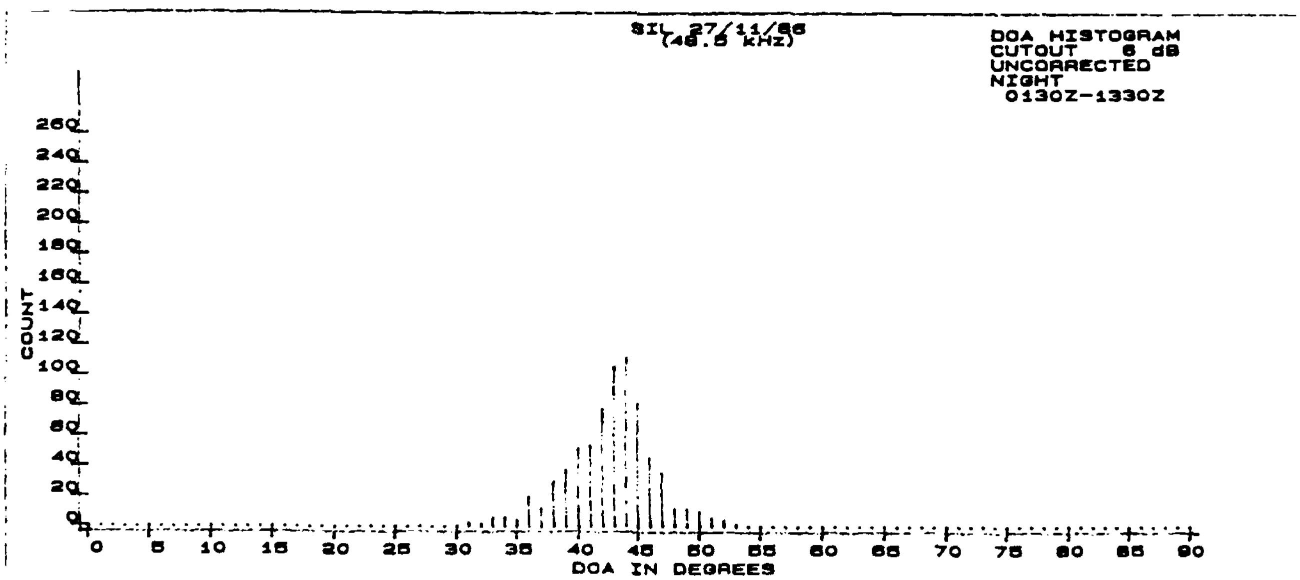
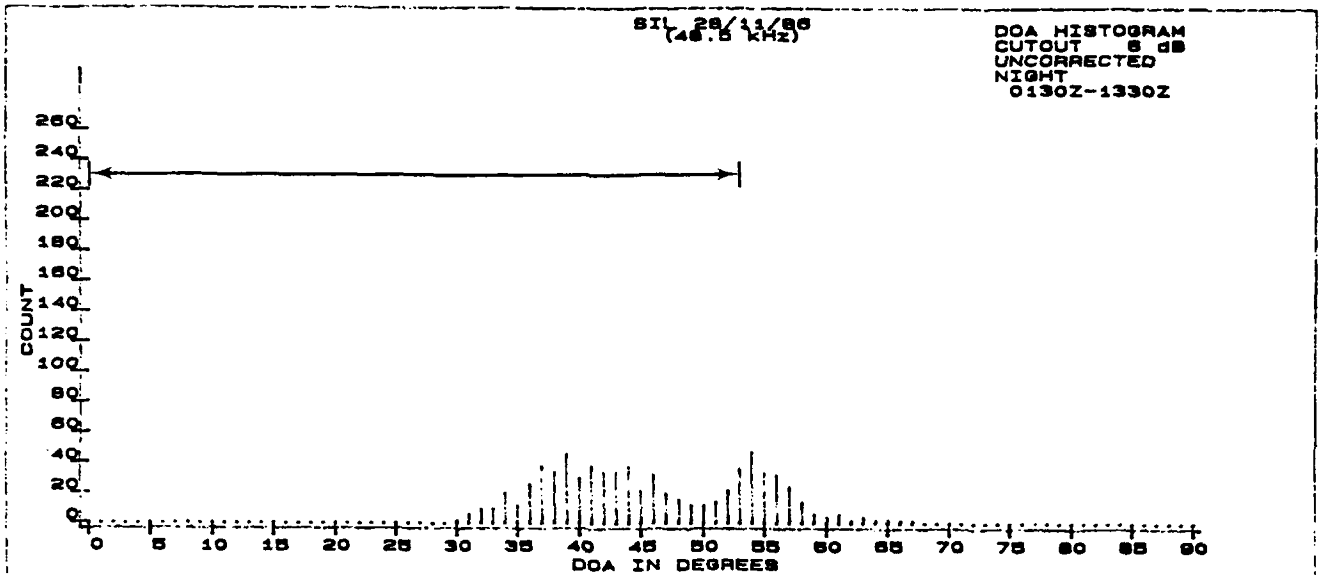
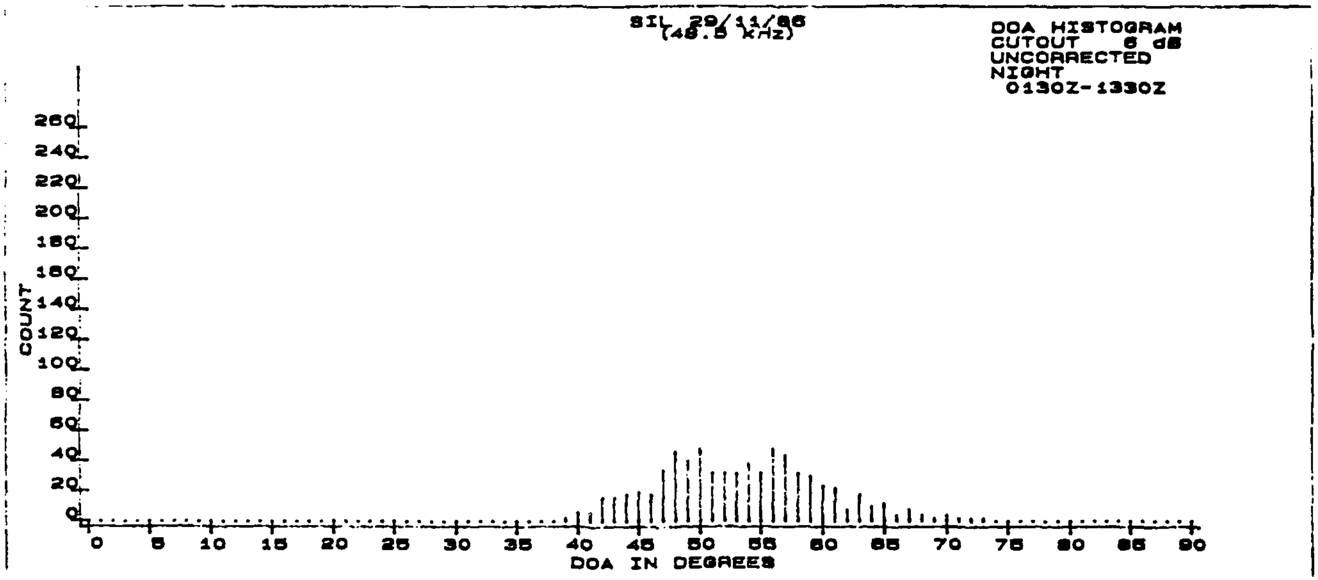


Figure 29. Histograms for Silver Creek to San Diego - Night.





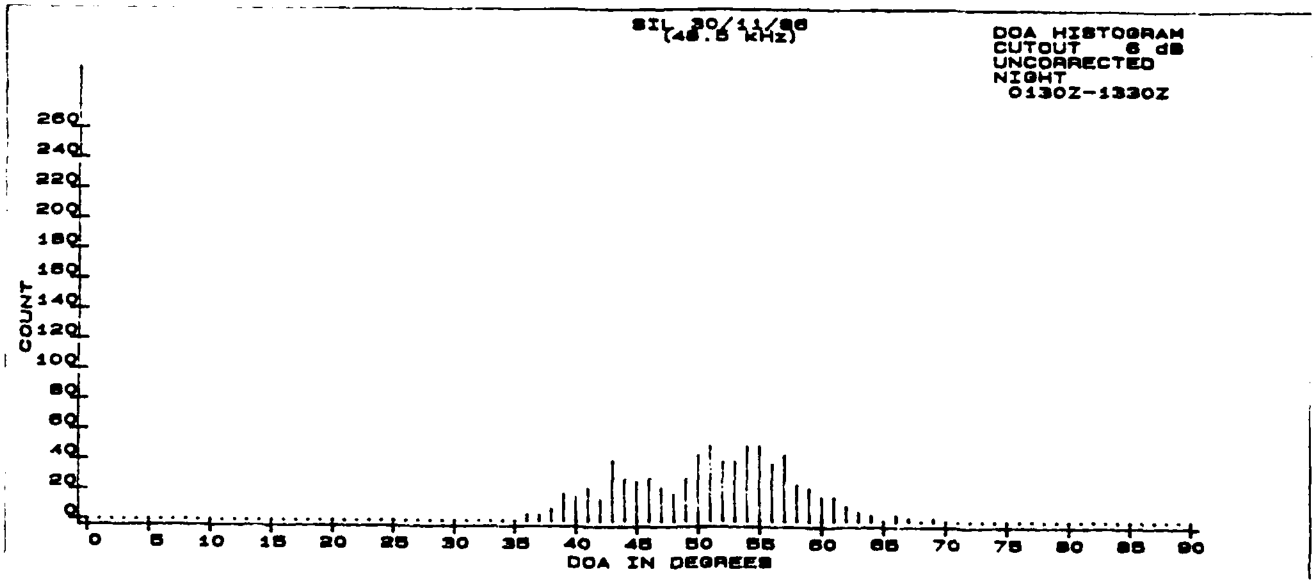


Figure 30. Histograms for Silver Creek to San Diego - Night.

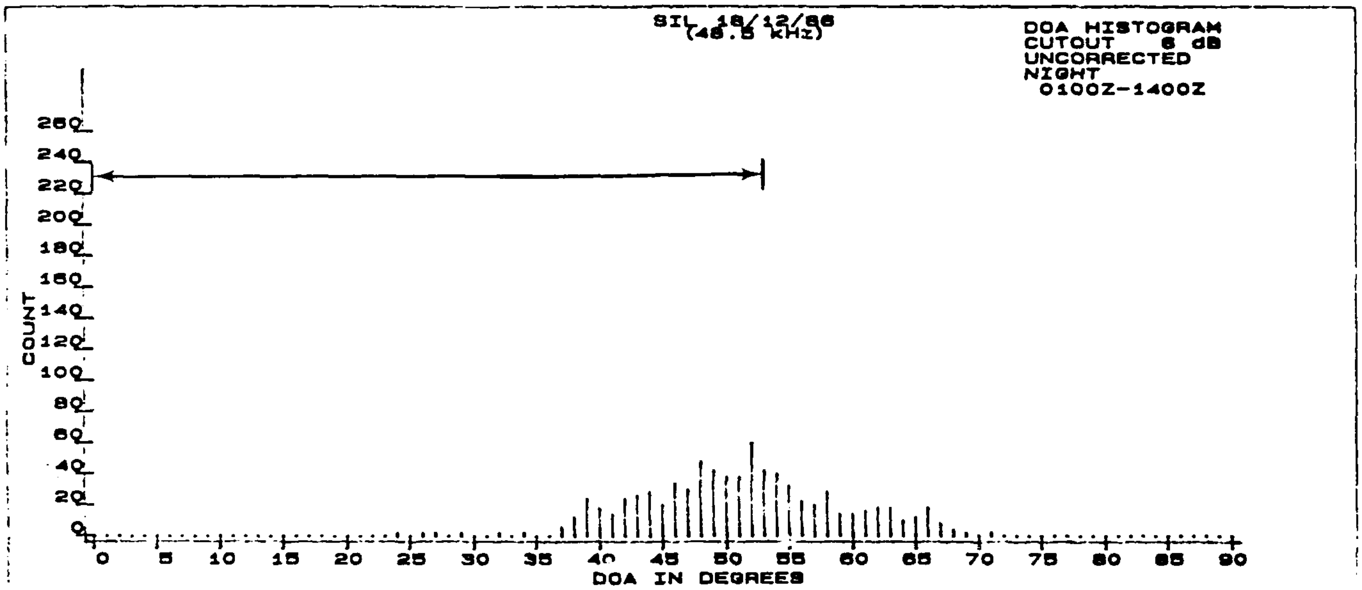


Figure 31. Histograms for Silver Creek to San Diego - Night.

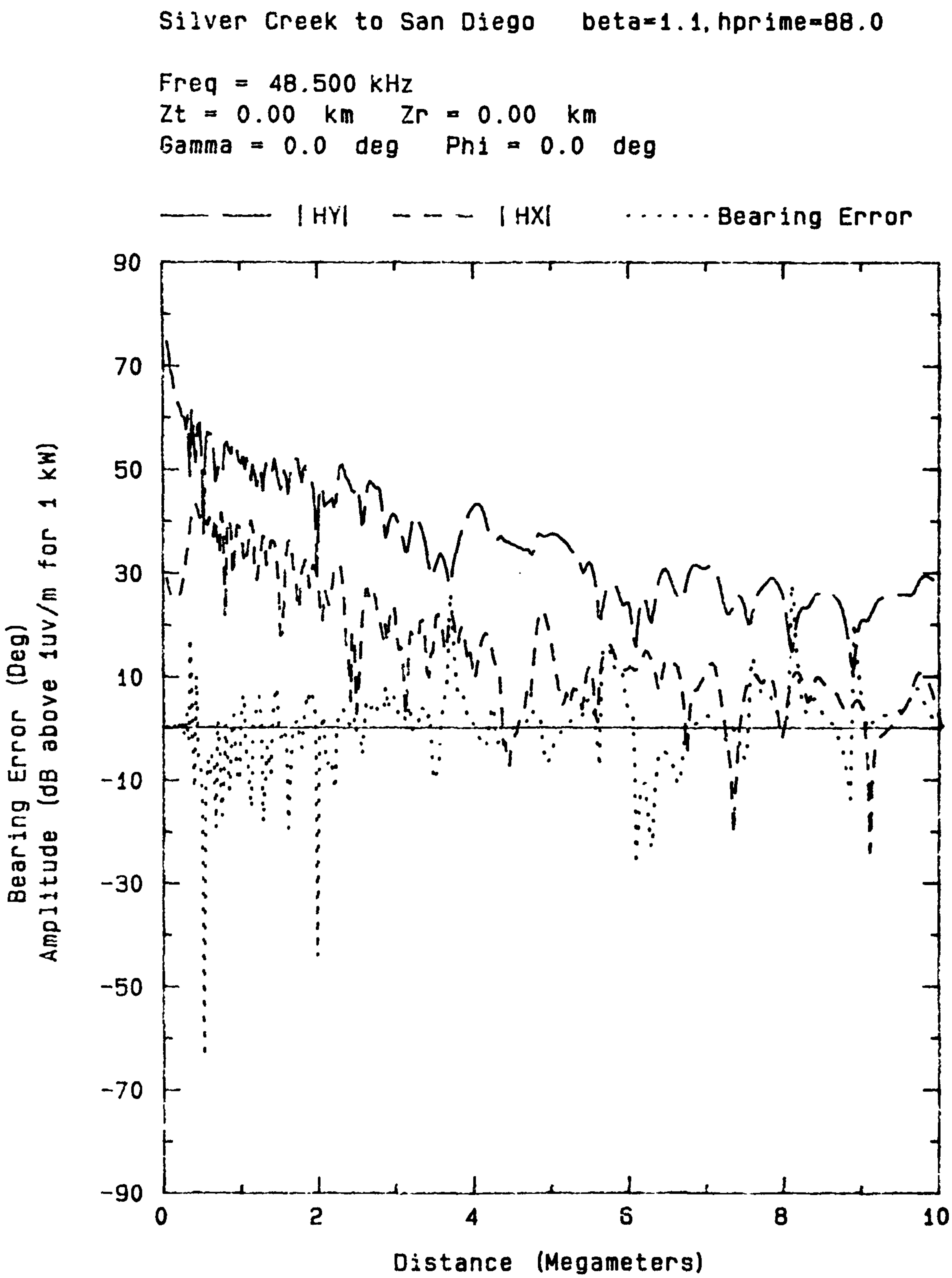


Figure 32. Sample range plot for Silver Creek to San Diego - Night.

APPENDIX A: PROGRAM LISTING

```
      parameter (maxmds=30)
      IMPLICIT REAL *8(A-H,O-Z)
      COMMON/HGTEMP/FF1(25,maxmds),FF3(25,maxmds)
      COMMON/TERM/NT,NTR
      COMMON/CAP/CAPI(25,maxmds,maxmds),TNORM(25,maxmds,maxmds)
      COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
     $             XTRA(3,3,25,maxmds),TOPHT(25),
     $             XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
     $             SIGMA(25),NRSLAB,NRMODE(25),NTMAX
      COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
     $             NTHSQ(25),KVRAOT,KVRATT,
     $             AVRKOT,AVRKTT,CONST,OMEGA,WAVENO
      COMMON/MCPLOT/R(400),DBy(400),DBx(400),ANGchi(400),
     $              IDPLOT,ISUB
      COMMON/XPLOT/XMIN,xmax,Xtic,YMIN,ymax,Ytic,SIZEX,SIZEY
      COMMON/HGINPT/GAMMA,PHI,ZT,ZR,SINGAM,COSGAM,SINPHI,COSPHI
      common/pltflg/iplflg
      DIMENSION Z(2)
      character*4 bcd(20)
      character*68 idplot
      REAL*4 R,DBy,dbx,angchi
      REAL*4 XMIN,xmax,Xtic,YMIN,ymax,Ytic,SIZEX,SIZEY
      COMPLEX*16 FF1,FF3
      COMPLEX*16 THETA,A,S,C,FOFR,IM,CAPI,TNORM
      complex*16 temp
      COMPLEX*16 XTRA,NTHSQ,T1,T2,T3,T4
      REAL*8 KVRAOT,KVRATT
      data IM/(0.0D0,1.0D0)/
      NAMELIST/DATUM/       RHOMAX,
     &   RHOMIN,DELTAX,NRSLAB,NTMAX,XVAL,
     $   DELRHO,IFIRST,LAST,IPLTOP,iplflg,
     $   XMIN,xmax,Xtic,YMIN,ymax,Ytic,SIZEX,SIZEY,
     $   GAMMA,PHI,ZT,ZR,IPRNTA
     $   ,INTFLG
      DATA TWOPI/6.283185D0/,VELITE/2.997928D5/,ALPHA/3.14D-4/,
     $   DEGRAD/1.745329D-2/
      DATA LAST/0/,IPRNTA/0/
C
      INTFLG=0
      iplflg=0
10    continue
      READ(5,DATUM)
      print datum
      write(*,'(/)')
      GAMMA = GAMMA*DEGRAD
      PHI = PHI*DEGRAD
      SINGAM = DSIN(GAMMA)
      COSGAM = DCOS(GAMMA)
      SINPHI = DSIN(PHI)
      COSPHI = DCOS(PHI)
      read(5,'(a68)') idplot
      write(*,'(1x,a68,/)') idplot
      DO M=1,NRSLAB
        nrmode(m)=1
        read(5,1020) rr,ff,aa,cc,bb,ss,ee,topht(m)
        print 1022,m,rr,ff,aa,cc,bb,ss,ee,topht(m)
        PRINT 102
        if(m .gt. 1 .and. ff .ne. freq ) then
```

```
          print *,'Check input records - mis-match on freq'
          stop
        endif
        freq=ff
        sigma(m)=ss
        epsr(m)=ee
205     k=nrmode(m)
        read(5,1023) indx1,temp,ipol1,t1,t2
        if(indx1 .gt. 0) then
          read(5,1023) indx2,theta(m,k),ipol2,t3,t4
c         get ey/hy
          if(ipol1 .eq. 1) then
            fofr(m,k)=t3/t1
          else
            fofr(m,k)=t2/(t3*t4)
          end if
          PRINT 103,THETA(M,K),T1,T2,T3,T4,FOFR(M,K),TOPHT(M)
          S(M,K) = zsin(THETA(M,K)*DEGRAD)
          C(M,K) = zcos(THETA(M,K)*DEGRAD)
          XTRA(1,1,M,K) = T1*S(M,K)**2
          XTRA(1,2,M,K) = T1*S(M,K)
          XTRA(1,3,M,K) = -T3*S(M,K)
          XTRA(2,1,M,K) = -T1*S(M,K)
          XTRA(2,2,M,K) = -T1
          XTRA(2,3,M,K) = T3
          XTRA(3,1,M,K) = -T3*T4*S(M,K)
          XTRA(3,2,M,K) = -T3*T4
          XTRA(3,3,M,K) = T2
          nrmode(m)=nrmode(m)+1
          go to 205
        endif
        nrmode(m)=nrmode(m)-1
      enddo
      NT = 1
      WAVE NO = TWO PI*1000.0*FREQ/VELITE
      CONST = 0.03248*WAVE NO/DSQRT(FREQ)
      OMEGA = TWO PI*FREQ*1000.
      KVRAOT = DEXP(DLOG(WAVE NO/ALPHA)/3.)
      KVRATT = KVRAOT**2
      AVRKOT = 1./KVRAOT
      AVRKTT = AVRKOT**2*0.5
      DO 130 L=1,NRSLAB
130   NTHSQ(L) = 1.+ALPHA*TOPHT(L)
      IFLG = 0
      DO 135 M=1,NRSLAB
      IF(M .NE. 1) IFLG=1
135   CALL HTINTL(CAPI,TNORM,IFLG,M,INTFLG)
      Z(1) = ZT
      Z(2) = ZR
      CALL HTGAIN(Z)
      DO 136 M=1,NRSLAB
      DO 136 K=1,NRMODE(m)
      XTRA(1,1,M,K) = XTRA(1,1,M,K)*FF1(M,K)**2
      XTRA(1,2,M,K) = XTRA(1,2,M,K)*FF1(M,K)**2
      XTRA(1,3,M,K) = XTRA(1,3,M,K)*FF1(M,K)*FF3(M,K)/FOFR(M,K)
      XTRA(2,1,M,K) = XTRA(2,1,M,K)*FF1(M,K)**2
      XTRA(2,2,M,K) = XTRA(2,2,M,K)*FF1(M,K)**2
      XTRA(2,3,M,K) = XTRA(2,3,M,K)*FF1(M,K)*FF3(M,K)/FOFR(M,K)
```

```
      XTRA(3,1,M,K) = XTRA(3,1,M,K)*FF1(M,K)*FF3(M,K)/FOFR(M,K)
      XTRA(3,2,M,K) = XTRA(3,2,M,K)*FF1(M,K)*FF3(M,K)/FOFR(M,K)
      XTRA(3,3,M,K) = XTRA(3,3,M,K)*FF3(M,K)**2/(FOFR(M,K)**2)
136   CONTINUE
      if(nrslab .eq. 1) then
        do j=1,nrmode(1)
          do k=1,nrmode(1)
            a(1,k,j)=(0.,0)
            if(k .eq. j) a(1,k,j)=(1.0,0.0)
          enddo
        enddo
        ntr=1
        go to 405
      endif
118   IF(XVAL(2) .GE. 0.) GO TO 111
      DO 112 L=1,NRSLAB
      DO 112 J=1,NRMODE(1)
      DO 112 K=1,NRMODE(1)
112   A(L,K,J) = 0.0
      DO 113 L=2,NRSLAB
      IF(XVAL(L) .GE. 0.) GO TO 114
113   CONTINUE
      NTR = nrslab
      GO TO 117
114   NTR = L-1
117   CONTINUE
      DO 116 J=1,NRMODE(ntr)
      DO 116 K=1,NRMODE(ntr)
116   IF(K .EQ. J) A(NTR,K,J)=(1.0,0.0)
      DO 401 M=ntr,nrslab
401   CALL MCSTEP(M)
      IF(IPRNTA .EQ. 0) GO TO 91
      PRINT 905
      DO 451 L=ntr,nrslab
      PRINT 900,L
      DO 451 J=1,NRMODE(1)
      DO 451 K=1,NRMODE(1)
      PRINT 901,J,K,A(L,J,K)
451   CONTINUE
91    IF(IPLTOP .EQ. 1) CALL MCFLD
      IF(IPLTOP .EQ. 2) CALL MCFLD2
      NT = NT+1
      DO 106 ME=2,nrslab
106   XVAL(ME) = XVAL(ME)+DELTAX
      IF(XVAL(NTR) .GE. 0. .AND. NT .LE. NTMAX) GO TO 118
      IF(NT .LE. NTMAX) GO TO 91
      IF(LAST .EQ. 0) GO TO 10
      stop
111   NTR = 1
      DO 120 L = 1,NRSLAB
      DO 120 K = 1, NRMODE(1)
      DO 120 J = 1, NRMODE(1)
      A(L,K,J) = 0.0
      IF(1 .eq. 1 .and. K .EQ. J) A(1,j,k) = (1.0,0.0)
  120 CONTINUE
C     THE LOOP 400 DETERMINES(A)
C     IN SUCCESSIVE SLABS.
      DO 400 M = 1,NRSLAB
```

```
      CALL MCSTEP(M)
      IF(NRSLAB .LE. 1) stop
  400 CONTINUE
405   continue
      IF(IPRNTA .EQ. 0) GO TO 90
      PRINT 905
      DO 450 L=1,NRSLAB
      PRINT 900,L
      DO 450 J=1,NRMODE(1)
      DO 450 K=1,NRMODE(1)
      PRINT 901,J,K,A(L,J,K)
450   CONTINUE
90    IF(IPLTOP .EQ. 1) CALL MCFLD
      IF(IPLTOP .EQ. 2) CALL MCFLD2
      NT = NT + 1
      DO 105 ME = 2,nrslab
      XVAL(ME) = XVAL(ME) + DELTAX
  105 CONTINUE
      IF(NT .LE. NTMAX) GO TO 90
      IF(LAST .EQ. 0) GO TO 10
      stop
102   FORMAT(5X,'THETA',15X,'T1',20X,'T2',20X,'T3',20X,'T4',20X,'FOFR',
     $ 10X,'TOPHT')
103   FORMAT(' ',2F7.3,2X, 5(2D10.3,2X),F4.1)
201   FORMAT(20A4)
202   FORMAT(' ',20A4)
900   FORMAT(1H ,14X,
     $ 'A = TOTAL CONVERSION COEFFICIENTS',6X,'SLAB NUMBER = ',I2,/)
901   FORMAT(14X,' J =',I2,5X,' K =', I2,5X,' A=',(E15.5,E15.5),/)
  905 FORMAT(1H1)
1020  format(1x,f7.0,3(2x,f8.0),2(2x,e10.0),2(2x,e5.0))
1022  format(/,' Slab ',i2,' R',f7.3,' F',f8.4,' A',f8.3,' C',f8.3,' M',
     $  f6.3,' S',1pe10.3,' E',0pf5.1,' T',f5.1)
1023  format(i1,2f9.0,i1,4e15.0)
      END
```

```
      SUBROUTINE HTINTL(CAPI,NORM,IFLG,M,INTFLG)
C  CALCULATE NORMALIZATION INTEGRALS AND INTEGRALS OF HEIGHT GAINS IN
C  ADJACENT SLABS.
      parameter (maxmds=30)
      IMPLICIT REAL *8(A-H,O-Z)
      COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
     $             XTRA(3,3,25,maxmds),TOPHT(25),
     $             XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
     $             SIGMA(25),NRSLAB,NRMODE(25),NTMAX
      COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
     $             NTHSQ(25),KVRAOT,KVRATT,
     $             AVRKOT,AVRKTT,CONST,OMEGA,WAVENO
      COMPLEX*16 NTHSQ
      COMPLEX*16 PTHA,H1TA,H2TA,H1PRTA,H2PRTA,HYTHA(maxmds),
     $   EYTHA(maxmds),HYTHPA(maxmds),EYTHPA(maxmds)
      COMPLEX*16 THETA,FOFR,A,S,C,SSQ,CSQ,IM,NGSQ,
     &   SQROOT,RTIORT,P0,PTH,H10,H20,H1PRM0,H2PRM0,CAPH10,CAPH20,
     &   A1ST,A2ND,A3RD,A4TH,DEN12,DEN34,DENMF,NURMF,
     &   H1T,H2T,H1PRMT,H2PRMT,HYTH(maxmds),EYTH(maxmds),HYTHPR(maxmds),
     $   EYTHPR(maxmds),
     &   HY0PR(maxmds),EY0PR(maxmds),EY0(maxmds),MULT,FAC1,FAC2,
     $   NORM(25,maxmds,maxmds),PS(maxmds),
     $   CAPI(25,maxmds,maxmds),PHYTH(maxmds),PHYTHP(maxmds),
     $   PEYTH(maxmds),PEYTHP(maxmds),PEY0(maxmds),
     &   PEY0PR(maxmds),PHY0PR(maxmds),XTRA
      REAL*8 KVRAOT,KVRATT
      DATA EPSLN0/8.85434D-12/
      data IM/(0.D0,1.D0)/
C
C
      DO 100 K = 1, NRMODE(m)
      SSQ = S(M,K)**2
      CSQ = C(M,K)**2
c     NGSQ = (EPSLON(M) - IM*SIGMA(M)/OMEGA)/EPSLN0
      ngsq=epsr(m)-(im*sigma(m))/(omega*epsln0)
      SQROOT = zsqrt(NGSQ - SSQ)
      RSQR = SQROOT
      IF(RSQR .LT. 0.) SQROOT=-SQROOT
      RTIORT = 1./NGSQ*SQROOT
      P0 = KVRATT*CSQ
      PTH = KVRATT*(NTHSQ(M)-SSQ)
      CALL MDHNKL(P0,H10,H20,H1PRM0,H2PRM0)
      CAPH10 = H1PRM0 + AVRKTT*H10
      CAPH20 = H2PRM0 + AVRKTT*H20
      A1ST = CAPH20 - IM*RTIORT*KVRAOT*H20
      A2ND = CAPH10 - IM*RTIORT*KVRAOT*H10
      A3RD = H2PRM0 - IM*KVRAOT*SQROOT*H20
      A4TH = H1PRM0 - IM*KVRAOT*SQROOT*H10
      DEN12 = H20*A2ND - H10*A1ST
      DEN34 = H20*A4TH - H10*A3RD
      CALL MDHNKL(PTH,H1T,H2T,H1PRMT,H2PRMT)
      HYTH(K) = (H2T*A2ND - H1T*A1ST)/DEN12
      EYTH(K) = (H2T*A4TH - H1T*A3RD)/DEN34*FOFR(M,K)
      HYTHPR(K) = (H2PRMT*A2ND - H1PRMT*A1ST)/DEN12
      EYTHPR(K) = (H2PRMT*A4TH - H1PRMT*A3RD)/DEN34*FOFR(M,K)
      HY0PR(K) = (H2PRM0*A2ND - H1PRM0*A1ST)/DEN12
      EY0PR(K) = (H2PRM0*A4TH - H1PRM0*A3RD)/DEN34*FOFR(M,K)
      IF(IFLG .EQ. 0) GO TO 100
```

```
      PTHA = KVRATT*(NTHSQ(M-1)-SSQ)
      CALL MDHNKL(PTHA,H1TA,H2TA,H1PRTA,H2PRTA)
      HYTHA(K) = (H2TA*A2ND-H1TA*A1ST)/DEN12
      EYTHA(K) = (H2TA*A4TH-H1TA*A3RD)/DEN34*FOFR(M,K)
      HYTHPA(K) = (H2PRTA*A2ND-H1PRTA *A1ST)/DEN12
      EYTHPA(K) = (H2PRTA*A4TH-H1PRTA*A3RD)/DEN34*FOFR(M,K)
  100 EY0(K) = FOFR(M,K)
      IF(INTFLG .EQ. 1) PRINT 906,M
      DO 240 J = 1,NRMODE(m)
      DO 240 K = 1,NRMODE(m)
      IF(J .EQ. K) GO TO 120
      MULT = AVRKOT/((S(M,J) - S(M,K))*WAVENO)
      FAC1 = EYTH(K)*EYTHPR(J) - EYTH(J)*EYTHPR(K) + HYTH(K)*HYTHPR(J)
     $    -HYTH(J)*HYTHPR(K)
      FAC2 = -EY0(K)*EY0PR(J) + EY0(J)*EY0PR(K) - HY0PR(J) + HY0PR(K)
      NORM(M,J,K) = MULT*(FAC1+FAC2)
      IF(INTFLG .EQ. 1) PRINT 908,M,J,K,NORM(M,J,K)
      GO TO 240
  120 MULT = 2.0*S(M,J)*KVRAOT/WAVENO
      PTH = KVRATT*(NTHSQ(M)-S(M,J)**2)
       P0 = KVRATT*C(M,J)**2
      FAC1 = EYTHPR(J)**2 + HYTHPR(J)**2 + PTH*(EYTH(J)**2 + HYTH(J)**2)
      FAC2 = -EY0PR(J)**2 - HY0PR(J)**2 - P0*(EY0(J)**2 + 1.0)
      NORM(M,J,K) = MULT*(FAC1+FAC2)
      IF(INTFLG .EQ. 1) PRINT 908,M,J,K,NORM(M,J,K)
  240 CONTINUE
      IF (IFLG  .EQ. 0) GO TO 500
      DO 400 K = 1, NRMODE(m)
      DO 400 J = 1, NRMODE(m-1)
      MULT = AVRKOT/((PS(J) - S(M,K))*WAVENO)
      FAC1 = EYTHA(K)*PEYTHP(J)-PEYTH(J)*EYTHPA(K)
     $+HYTHA(K)*PHYTHP(J)-PHYTH(J)*HYTHPA(K)
      FAC2 = -EY0(K)*PEY0PR(J) + PEY0(J)*EY0PR(K) -PHY0PR(J) + HY0PR(K)
      CAPI(M,K,J) = MULT*(FAC1+FAC2)
      IF(INTFLG .EQ. 1) PRINT 910,M,K,J,CAPI(M,K,J)
  400 CONTINUE
  500 DO 600 J = 1, NRMODE(m)
      PS(J) = S(M,J)
      PHYTH(J) = HYTH(J)
      PHYTHP(J) = HYTHPR(J)
      PEYTH(J) = EYTH(J)
      PEYTHP(J) = EYTHPR(J)
      PHY0PR(J) = HY0PR(J)
      PEY0(J) = EY0(J)
      PEY0PR(J) = EY0PR(J)
  600 CONTINUE
720   CONTINUE
      RETURN
906   FORMAT('0',20X,'INTEGRALS IN SLAB',I3,/)
908   FORMAT(21X,'NORM(',I1,',',I1,',',I1,') =',2D13.6)
910   FORMAT(21X,'CAPI(',I1,',',I1,',',I1,') =',2D13.6)
      END
```

```
      SUBROUTINE HTGAIN(Z)
C  COMPUTE EZ,EX,EY HEIGHT GAINS FOR TRANSMITTER AND RECEIVER.
      parameter (maxmds=30)
      IMPLICIT COMPLEX*16(A-H,O-Z)
      COMMON/HGTEMP/FF1(25,maxmds),FF3(25,maxmds)
      COMMON/HTGN/F(4,25,maxmds,2)
      COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
     $             XTRA(3,3,25,maxmds),TOPHT(25),
     $             XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
     $             SIGMA(25),NRSLAB,NRMODE(25),NTMAX
      COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
     $             NTHSQ(25),KVRAOT,KVRATT,
     $             AVRKOT,AVRKTT,CONST,OMEGA,WAVENO
      COMPLEX*16 zsqrt
      REAL*8 DEXP
      COMPLEX*16 NGSQ,IM,NTHSQ
      REAL*8 XVAL,FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr,SIGMA
      REAL*8 KVRAOT,KVRATT,AVRKOT,AVRKTT,CONST,OMEGA,WAVENO
      REAL*8 Z(2),EPSLNO,ALPHA,FAC1
      REAL*8 RSQR
      REAL*8 TOPHT
      data IM/(0.D0,1.D0)/
      data EPSLNO/8.85434D-12/,ALPHA/3.14D-4/
c
      DO 100 M=1,NRSLAB
c     NGSQ = (EPSLON(M)-IM*SIGMA(M)/OMEGA)/EPSLNO
      ngsq=epsr(m)-(im*sigma(m))/(omega*epsln0)
      DO 100 K=1,NRMODE(m)
      SSQ = S(M,K)**2
      SQROOT = zsqrt(NGSQ-SSQ)
      CSQ = C(M,K)**2
      RSQR = SQROOT
      IF(RSQR .LT. 0.) SQROOT=-SQROOT
      DO 100 IZ=1,2
      Q = KVRATT*(CSQ+ALPHA*Z(IZ))
      Q0 = KVRATT*CSQ
      CALL MDHNKL(Q0,H10,H20,H1PRM0,H2PRM0)
      CALL MDHNKL(Q,H1,H2,H1PRM,H2PRM)
      CAPH10 = H1PRM0+AVRKTT*H10
      CAPH20 = H2PRM0+AVRKTT*H20
      FAC2 = IM*KVRAOT*SQROOT
      FAC3 = FAC2/NGSQ
      F1 = -(CAPH20-FAC3*H20)
      F2 =   CAPH10-FAC3*H10
      F3 = -(H2PRM0-FAC2*H20)
      F4 =   H1PRM0-FAC2*H10
      FAC1 = DEXP(ALPHA/2.*Z(IZ))
      F(1,M,K,IZ) = FAC1*(F1*H1+F2*H2)
      F(2,M,K,IZ) = ALPHA/(IM*2.*WAVENO)*F(1,M,K,IZ)+1./IM*AVRKOT*FAC1*
     $ (F1*H1PRM+F2*H2PRM)
      F(3,M,K,IZ) = F3*H1+F4*H2
      f(4,m,k,iz) = -im*avrkot*(f3*h1prm+f4*h2prm)
      FF1(M,K) = F1*H10+F2*H20
      FF3(M,K) = F3*H10+F4*H20
      F(1,M,K,IZ) = F(1,M,K,IZ)/FF1(M,K)
      F(2,M,K,IZ) = F(2,M,K,IZ)/FF1(M,K)
      F(3,M,K,IZ) = F(3,M,K,IZ)*FOFR(M,K)/FF3(M,K)
      F(4,M,K,IZ) = F(4,M,K,IZ)*FOFR(M,K)/FF3(M,K)
```

```
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MCSTEP(M)
C  COMPUTE GENERALIZED MODE CONVERSION COEFFICIENTS.
      parameter (maxmds=30)
      IMPLICIT REAL *8(A-H,O-Z)
      COMMON/TERM/NT,NTR
      COMMON/CAP/CAPI(25,maxmds,maxmds),TNORM(25,maxmds,maxmds)
      COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
     $             XTRA(3,3,25,maxmds),TOPHT(25),
     $             XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
     $             SIGMA(25),NRSLAB,NRMODE(25),NTMAX
      COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
     $             NTHSQ(25),KVRAOT,KVRATT,
     $             AVRKOT,AVRKTT,CONST,OMEGA,WAVENO
      COMPLEX*16 zexp
      COMPLEX*16 NTHSQ
      COMPLEX*16 THETA,FOFR,A,S,C,TNORM,CAPI,
     $   IM,B(maxmds),ANS(maxmds),TS(maxmds,maxmds),XTRA
      REAL*8 KVRAOT,KVRATT
      REAL*4 ERR
      data IM/(0.D0,1.D0)/
C
C
      MP = M-1
      IF(M .EQ. NTR) RETURN
      DO N=1,maxmds
        B(N) = (0.,0.)
      enddo
      IF(MP .ne. NTR) then
        DO K=1,NRMODE(ntr)
          DO L=1,NRMODE(m)
            DO J=1,NRMODE(m)
              TS(L,J) = TNORM(M,L,J)
            enddo
          enddo
          do l=1,nrmode(m)
            do j=1,nrmode(mp)
              B(L)=B(L)+A(MP,J,K)*zexp(-IM*WAVENO*S(MP,J)*(XVAL(M)-
     &              XVAL(MP)))*CAPI(M,L,J)
            enddo
          enddo
          CALL CLINEQ(TS,B,ANS,NRMODE(m),maxmds,0,ERR)
          DO I=1,NRMODE(m)
c           A(M,I,K) = ANS(I)*S(M,I)/S(NTR,K)
            A(M,I,K) = ANS(I)
          enddo
          DO N=1,maxmds
            B(N) = (0.,0.)
          enddo
        enddo
      else
        DO K=1,NRMODE(mp)
          DO LL=1,NRMODE(m)
            DO L=1,NRMODE(m)
              TS(LL,L) = TNORM(M,LL,L)
              B(L) = CAPI(M,L,K)
            enddo
          enddo
          CALL CLINEQ(TS,B,ANS,NRMODE(m),maxmds,0,ERR)
```

```
            DO J-1,NRMODE(m)
c             A(M,J,K) - ANS(J)*S(M,J)/S(NTR,K)
              A(M,J,K) - ANS(J)
            enddo
          enddo
        endif
        RETURN
        END
```

```
      SUBROUTINE MDHNKL (Z,H1,H2,H1PRME,H2PRME)
C   COMPUTE MODIFIED HANKEL FUNCTIONS OF ORDER ONE THIRD
      IMPLICIT REAL *8 (A-H,O-Z)
      COMPLEX*16 zsqrt,zexp
      REAL*8 zabs
      COMPLEX*16 Z,I,H1,H2,H1PRME,H2PRME,ZPOWER,TERM1,TERM2,
     $           TERM3,ZTERM,TERM,SUM1,SUM2,SUM3,SUM4,SQRTZB,
     $           EXP1,EXP2,EXP3,EXP4,EXP5,GM2F,GPMFP,MPOWER,BETA,RTZ,
     $           CONST1,CONST2,CONST3,CONST4
      DIMENSION A(23), B(23), C(23), D(23), CAP(14)
      DATA A/
     $   9.30436716930000D-01,3.10145572309700D 01,2.06763714873160D 02,
     $   5.74343652425450D 02,8.70217655190080D 02,8.28778719228640D 02,
     $   5.41685437404340D 02,2.57945446383020D 02,9.34584950663100D 01,
     $   2.66263518707400D 01,6.12100043005600D 00,1.15928038448000D 00,
     $   1.84012759441000D-01,2.48330309640000D-02,2.88420801000000D-03,
     $   2.91334142000000D-04,2.58274950000000D-05,2.02568600000000D-06,
     $   1.41557000000000D-07,8.87000000000000D-09,5.01000000000000D-10,
     $   2.60000000000000D-11,1.00000000000000D-12/
      DATA B/
     $   6.78298725140000D-01,1.13049787524000D 01,5.38332321543100D 01,
     $   1.19629404787350D 02,1.53371031778650D 02,1.27809193148880D 02,
     $   7.47422182157200D 01,3.23559386215200D 01,1.07853128738400D 01,
     $   2.85325737403000D 00,6.13603736351000D-01,1.09376780098000D-01,
     $   1.64229399550000D-02,2.10550512200000D-03,2.33167788000000D-04,
     $   2.25282890000000D-05,1.91567100000000D-06,1.44470000000000D-07,
     $   9.72900000000000D-09,5.89000000000000D-10,3.20000000000000D-11,
     $   2.00000000000000D-12,0.00000000000000D 00/
      DATA C/
     $   4.65218358460000D-01,6.20291144619000D 00,2.58454643591500D 01,
     $   5.22130593114000D 01,6.21584039421500D 01,4.87516893663900D 01,
     $   2.70842718702700D 01,1.12150194079600D 01,3.59455750255000D 00,
     $   9.18150064510000D-01,1.91281263439000D-01,3.31222966990000D-02,
     $   4.84244103800000D-03,6.05683682000000D-04,6.55501820000000D-05,
     $   6.19859900000000D-06,5.16550000000000D-07,3.82200000000000D-08,
     $   2.52800000000000D-09,1.50000000000000D-10,8.00000000000000D-12,
     $   0.00000000000000D 00,0.00000000000000D 00/
      DATA D/
     $   6.78298725140000D-01,4.52199150096200D 01,3.76832625080150D 02,
     $   1.19629404787350D 03,1.99382341312250D 03,2.04494709038206D 03,
     $   1.42010214609865D 03,7.11830649673510D 02,2.69632821846030D 02,
     $   7.98912064729000D 01,1.90217158268800D 01,3.71881052333900D 00,
     $   6.07648778323000D-01,8.42202048960000D-02,1.00262148690000D-02,
     $   1.03630127800000D-03,9.38678690000000D-05,7.51243500000000D-06,
     $   5.35074000000000D-07,3.41350000000000D-08,1.96200000000000D-09,
     $   1.02000000000000D-10,5.00000000000000D-12/
      DATA CAP/
     $   1.04166666666667D-01,8.35503472222222D-02,1.28226574556327D-01,
     $   2.91849026464140D-01,8.81627267443758D-01,3.32140828186277D 00,
     $   1.49957629868626D 01,7.89230130115870D 01,4.74451538868000D 02,
     $   3.20749009100000D 03,2.40865496000000D 04,1.98923120000000D 05,
     $   1.79190200000000D 06,1.74843770000000D 07/
C
      DATA I/(0.D0,1.D0)/
      DATA ROOT3/1.73205080756888D 00/
      DATA ALPHA/8.53667218838951D-01/
      DATA CONST1/( 2.58819045102522D-01,-9.65925826289067D-01)/
      DATA CONST2/( 2.58819045102522D-01, 9.65925826289067D-01)/
```

```
      DATA CONST3/(-9.65925826289067D-01, 2.58819045102522D-01)/
      DATA CONST4/(-9.65925826289067D-01,-2.58819045102522D-01)/
C
      ZPOWER=1.0
      SUM3=0.0
      SUM4=0.0
      ZMAG=zabs(Z)
      IF(ZMAG .GT. 4.2) GO TO 70
      IF(ZMAG .GE. 3.2) GO TO 10
      N=12
      GO TO 30
10    IF(ZMAG .GE. 4.1) GO TO 20
      N=15
      GO TO 30
20    N=23
30    SUM1=0.
      SUM2=0.
      ZTERM=-Z**3/200.0
      DO 50 M=1,N
      SUM1=SUM1+A(M)*ZPOWER
      SUM2=SUM2+B(M)*ZPOWER
      SUM3=SUM3+C(M)*ZPOWER
      SUM4=SUM4+D(M)*ZPOWER
      ZPOWER=ZPOWER*ZTERM
      IF(zabs(ZPOWER) .LE. 1.0D-30) GO TO 60
50    CONTINUE
60    GM2F=I*(Z*SUM2-2.*SUM1)/ROOT3
      GPMFP=I*(SUM4+2.*Z*Z*SUM3)/ROOT3
      H1=Z*SUM2+GM2F
      H2=H1-2.0*GM2F
      H1PRME=SUM4+GPMFP
      H2PRME=H1PRME-2.0*GPMFP
      RETURN
C
70    SUM1=1.0
      SUM2=1.0
      RTZ=zsqrt(Z)
      SQRTZB=RTZ*Z
      ZTERM=I/SQRTZB
      MPOWER=1.0
      TERM=-1.5/Z
      DO 80 M=1,14
      ZPOWER=ZPOWER*ZTERM
      MPOWER=MPOWER*(-ZTERM)
      TERM1=CAP(M)*ZPOWER
      TERM2=CAP(M)*MPOWER
      SUM1=SUM1+TERM1
      SUM2=SUM2+TERM2
      SUM3=SUM3+M*TERM1
      SUM4=SUM4+M*TERM2
80    CONTINUE
      SUM3=SUM3*TERM
      SUM4=SUM4*TERM
      EXP1=zexp(2.*I*SQRTZB/3.)
      EXP2=EXP1*CONST1
      EXP3=CONST2/EXP1
      EXP4=CONST3*EXP1
      EXP5=CONST4/EXP1
```

```
      BETA=ALPHA/zsqrt(RTZ)
      ZREAL=Z
      ZIMAG=-I*Z
      IF (ZREAL.GE.0.0.OR.ZIMAG.GE.0.0)GO TO 90
      H1=BETA*(EXP2*SUM2+EXP5*SUM1)
      H1PRME=BETA*(EXP2*(SUM2*(-0.25/Z+I*RTZ)+SUM4)+EXP5*(SUM1*(-0.25/Z
     $       -I*RTZ)+SUM3))
      GO TO 110
90    H1=BETA*EXP2*SUM2
      H1PRME=BETA*EXP2*(SUM2*(-0.25/Z+I*RTZ)+SUM4)
110   IF (ZREAL.GE.0.0.OR.ZIMAG.LT.0.0)GO TO 120
      H2=BETA*(EXP3*SUM1+EXP4*SUM2)
      H2PRME=BETA*(EXP3*(SUM1*(-0.25/Z-I*RTZ)+SUM3)+EXP4*(SUM2*(-0.25/Z
     $       +I*RTZ)+SUM4))
      RETURN
120   H2=BETA*EXP3*SUM1
      H2PRME=BETA*EXP3*(SUM1*(-0.25/Z-I*RTZ)+SUM3)
      RETURN
      END
      SUBROUTINE MAGANG(ARG,MAG,ANGLE)
      IMPLICIT REAL *8(A-H,O-Z)
      REAL*8 DSQRT,dacos
      COMPLEX*16 ARG,IM
      REAL*8 MAG
      DATA RDTDEG/5.729577951D+01/
      data IM/(0.D0,1.D0)/
c
      ENTRY MGNGLE(ARG,MAG,ANGLE)
      ARGRAL = ARG
      ARGMAG = -IM*ARG
      MAG = DSQRT(ARGRAL*ARGRAL + ARGMAG*ARGMAG)
      IF(MAG .EQ. 0.0) GO TO 10
      COSQ = ARGRAL/MAG
      IF (COSQ .LT. -1.0.AND. COSQ .GT. -1.01) COSQ = -1.0
      IF(COSQ .GT. 1.0.AND. COSQ .LT. 1.01) COSQ = 1.0
    5 ANGLE = dacos(COSQ)*RDTDEG
      IF(ARGMAG .LT. 0.0) ANGLE = 360.0 - ANGLE
      RETURN
   10 COSQ = 0.0
      GO TO 5
      END
      SUBROUTINE CLIN EQ (A, B, X, N, N DIM, IFLAG, ERR)
C
C   CLIN EQ USES L-U DECOMPOSITION TO
C   FIND THE TRIANGULAR MATRICES L, U
C   SUCH THAT  L * U = A.  L AND U ARE
C   STORED IN A.  THIS FORM IS USED WITH
C   BACK-SUBSTITUTION TO FIND THE SOLN
C   X OF   A * X = L * U * X = B.
C   N IS THE NUMBER OF EQUATIONS AND
C   N DIM IS THE DIMENSION OF ALL ARRAYS
C   IN THE PARAMETER LIST.
C
C   IF IFLAG = 0, L, U, AND X ARE
C   COMPUTED.
C   IF IFLAG IS NON-ZERO, IT IS ASSUMED
C   THAT L AND U HAVE BEEN COMPUTED IN
C   A PREVIOUS CALL AND ARE STILL STORED
```

```
C   IN A.  THUS ONLY X IS COMPUTED.
C   ERR  IS THE ESTIMATED RELATIVE
C   ERROR OF THE SOLUTION VECTOR.
C
      COMPLEX*16  A, B, X, T
      INTEGER*2  IROW
      DIMENSION  A(N DIM, N DIM),
     $  B(N DIM), X(N DIM)
      DIMENSION  IROW(50), Q(50)
      DATA  EPS /1.0E-15/
C
C
      IF (N.GT.50)  GO TO 900
      IF (IFLAG.NE.0)  GO TO 600
      DO 050  I = 1,N
      Q(I) = 0.0
      DO 040  J = 1,N
      QQ = zabs (A(I,J))
  040 IF (Q(I).LT.QQ)  Q(I) = QQ
      IF (Q(I).EQ.0.0)  GO TO 901
  050 CONTINUE
      ERR = EPS
      PPIV = 0.0
      DO 100  I = 1,N
  100 IROW(I) = I
C
      DO 500  L = 1,N
      PIVOT = 0.0
      K = L - 1
      DO 240  I = L,N
      IF (K.LT.1)  GO TO 230
      DO 220  J = 1,K
  220 A(I,L) = A(I,L) - A(J,L) * A(I,J)
  230 F = zabs (A(I,L)) / Q(I)
      IF (PIVOT.GT.F)  GO TO 240
      PIVOT = F
      NPIVOT = I
  240 CONTINUE
      IF (PIVOT.EQ.0.0)  GO TO 901
      IF (PPIV.LE.PIVOT)  GO TO 250
      ERR = ERR * PPIV / PIVOT
      IF (ERR.GE.1.0)  GO TO 901
  250 PPIV = PIVOT
      IF (NPIVOT.EQ.L)  GO TO 280
      Q(NPIVOT) = Q(L)
      J = IROW(L)
      IROW(L) = IROW(NPIVOT)
      IROW(NPIVOT) = J
      DO 260  I = 1,N
      T = A(L,I)
      A(L,I) = A(NPIVOT,I)
      A(NPIVOT,I) = T
  260 CONTINUE
  280 IF (L.EQ.N)  GO TO 500
      T = (1.0D0,0.0D0) / A(L,L)
      K = L + 1
      M = L - 1
      DO 450  I = K,N
```

```
      IF (M.LT.1)  GO TO 400
      DO 350  J = 1,M
  350 A(L,I) = A(L,I) - A(L,J) * A(J,I)
  400 A(L,I) = T * A(L,I)
  450 CONTINUE
  500 CONTINUE
      IF (ERR.GT.1.0E-5)   PRINT 998, ERR
C
C
  600 DO 620  I = 2,N
  620 X(I) = (0.0D0,0.0D0)
      J = IROW(1)
      X(1) = B(J) / A(1,1)
      DO 700  I = 2,N
      J = IROW(I)
      K = I - 1
      DO 650  L = 1,K
  650 X(I) = X(I) + A(I,L) * X(L)
      X(I) = (B(J) - X(I)) / A(I,I)
  700 CONTINUE
      K = N - 1
      DO 800  I = 1,K
      J = N - I
      M = J + 1
      DO 800  L = M,N
      X(J) = X(J) - X(L) * A(J,L)
  800 CONTINUE
      RETURN
C
  900 PRINT 999
      ERR = 1.0
      RETURN
  901 PRINT 997
      ERR = 1.0
      RETURN
  997 FORMAT ('1ERROR IN CLIN EQ, MATRIX IS SINGULAR')
  998 FORMAT (' CAUTION-',
     $ ' CLIN EQ HAS DECOMPOSED AN ILL-CONDITIONED MATRIX.',/,
     $ ' RESULTS WILL HAVE RELATIVE ERROR =',E11.2)
  999 FORMAT ('1ERROR IN CLIN EQ, MATRIX SIZE GREATER THAN 50')
      END
```

```
      SUBROUTINE MCFLD
      parameter (maxmds=30)
      IMPLICIT REAL *8(A-H,O-Z)
C    COMPUTE FIELDS FROM XVAL MIN TO XVAL MAX FOR TWO XMTR-RCVR DISTANCES
C    AT DELTAX INTERVALS
C
      COMMON/TERM/NT,NTR
      COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
     $              XTRA(3,3,25,maxmds),TOPHT(25),
     $              XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
     $              SIGMA(25),NRSLAB,NRMODE(25),NTMAX
      COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
     $              NTHSQ(25),KVRAOT,KVRATT,
     $              AVRKOT,AVRKTT,CONST,OMEGA,WAVENO
      character*68 idplot
      COMMON/MCPLOT/R(400),DBy(400),DBx(400),ANGchi(400),
     $               IDPLOT,ISUB
      COMMON/HTGN/F(4,25,maxmds,2)
      COMMON/HGINPT/GAMMA,PHI,ZT,ZR,SINGAM,COSGAM,SINPHI,COSPHI
      common/pltflg/iplflg
      REAL*4 R,DBy,dbx,angchi
      real*8 num
      REAL*8 KVRAOT,KVRATT
      complex*16 tahy,tahx
      COMPLEX*16 SOLNA(maxmds,3),THETA,A,S,C,XTRA,TB,FOFR,F,NTHSQ,IM
      DATA ERAD/6.370D3/
      data IM/(0.0D0,1.0D0)/
C
C
      MP=-10
      RHO = RHO MIN
      DO 1 LL=2,NRSLAB
      IF(XVAL(LL)-RHO .GE. 0.) GO TO 2
1     CONTINUE
      M=nrslab
      GO TO 3
2     M = LL-1
3     CONTINUE
      IF(M .EQ. MP) GO TO 720
      DO 710 L=1,3
      DO 710  J = 1,NRMODE(m)
      SOLN A(J,L) = (0.0,0.0)
      DO 710  K = 1,NRMODE(ntr)
      IF(M .NE. NTR) GO TO 35
      if(l .eq. 1) then
      SOLN A(J,L) = SOLN A(J,L)
     $                         +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
     $COSGAM     +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
     $COSPHI   +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
     $SINPHI)/(-s(ntr,k))
      else
      SOLN A(J,L) = SOLN A(J,L)
     $                         +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
     $COSGAM     +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
     $COSPHI   +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
     $SINPHI)
      endif
      GO TO 710
```

```
35    continue
      if(l .eq. 1) then
      SOLN A(J,L) = SOLN A(J,L)
     $                     +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
     $COSGAM    +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
     $COSPHI   +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
     $SINPHI)
     $ *zexp(-IM*WAVENO*S(NTR,K)*XVAL(NTR+1))/(-s(ntr,k))
      else
      SOLN A(J,L) = SOLN A(J,L)
     $                     +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
     $COSGAM    +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
     $COSPHI   +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
     $SINPHI)
     $ *zexp(-IM*WAVENO*S(NTR,K)*XVAL(NTR+1))
      endif
  710 CONTINUE
C
720   CONTINUE
      tahy = (0.0,0.0)
      tahx = (0.0,0.0)
      DO J=1,NRMODE(m)
        IF(M .eq. NTR) then
          TB =zexp(-IM*WAVENO*S(M   ,J)*RHO)
        else
          TB =zexp(IM*WAVENO*S(M   ,J)*(XVAL(M   ) - RHO))
        endif
        tahy=tahy+SOLNA(J,1)*TB*F(1,M,J,2)
        tahx=tahx+SOLNA(J,3)*TB*F(4,M,J,2)
      enddo
      tahy=tahy*CONST/DSQRT(DSIN(RHO/ERAD))
      tahx=tahx*CONST/DSQRT(DSIN(RHO/ERAD))
      tahyr=tahy
      tahyi=-im*tahy
      tahxr=tahx
      tahxi=-im*tahx
      phshy=datan2(tahyi,tahyr)
      phshx=datan2(tahxi,tahxr)
      amphy=dsqrt(tahyr*tahyr+tahyi*tahyi)
      amphx=dsqrt(tahxr*tahxr+tahxi*tahxi)
      beta=datan2(amphy,amphx)
      delta=phshy-phshx
      num=dsin(2.0*beta)*dcos(delta)
      den=dcos(2.0*beta)
      psi=0.5*datan2(num,den)*57.295779
      if(psi .lt. 0.0) psi=psi+180.0
      chi=90.0-psi
      ampy=10.0*dlog10(dmax1(1.0d-30,amphy*amphy)*1.0d12)
      ampx=10.0*dlog10(dmax1(1.0d-30,amphx*amphx)*1.0d12)
      R(NT) = XVAL(2)
      dby(nt) = ampy
      dbx(nt) = ampx
      angchi(nt) = chi
      MP = M
      IF(NT .NE. NTMAX) RETURN
      PGAMMA = GAMMA/1.745329D-2
      PPHI = PHI/1.745329D-2
      PRINT 927,PGAMMA,PPHI,ZT,ZR
```

```
927   FORMAT(//,' GAMMA(DEG)=',F6.1,'  PHI(DEG)=',F6.1,'  ZT(KM)=',F7.2,
     $'  ZR(KM)=',F7.2)
      print 929
929   FORMAT(/,13X,'RHO-KM',3X,'MAG(HY)-DB',3X,'MAG(HX)-DB',3x,
     $        'DOA ERROR-DEG')
      DO JJ=1,NTMAX
        PRINT 908,R(JJ),dby(jj),dbx(jj),angchi(jj)
908     FORMAT(9X,F10.2,2x,F10.5,3x,F10.5,3x,F10.5)
      enddo
      write(*,'(/)')
      IF (iplflg.EQ.0)  RETURN
      CALL MCPLTS
      RETURN
      END
```

```
      SUBROUTINE MCFLD2
      parameter (maxmds=30)
      IMPLICIT REAL *8(A-H,O-Z)
C    COMPUTE FIELDS FROM RHO MIN TO RHO MAX
C    AT DEL RHO INTERVALS.
C
      COMMON/TERM/NT,NTR
      COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
     $               XTRA(3,3,25,maxmds),TOPHT(25),
     $               XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
     $               SIGMA(25),NRSLAB,NRMODE(25),NTMAX
      COMMON/MCSTOR/A(25,maxmds,maxmds),S(25,maxmds),C(25,maxmds),
     $               NTHSQ(25),KVRAOT,KVRATT,
     $               AVRKOT,AVRKTT,CONST,OMEGA,WAVENO
      character*68 idplot
      COMMON/MCPLOT/R(400),DBy(400),DBx(400),ANGchi(400),
     $                IDPLOT,ISUB
      COMMON/HTGN/F(4,25,maxmds,2)
      COMMON/HGINPT/GAMMA,PHI,ZT,ZR,SINGAM,COSGAM,SINPHI,COSPHI
      common/pltflg/iplflg
      REAL*4 R,DBy,dbx,angchi
      COMPLEX*16 SOLNA(maxmds,3)
      COMPLEX*16 THETA,A,S,C,XTRA,TB,IM,FOFR,F,NTHSQ
      complex*16 tahy,tahx
      REAL*8 KVRAOT,KVRATT
      real*8 num
      DATA ERAD/6.370D3/
      data IM/(0.D0,1.D0)/
C
C
      ISUB = 1
      DBMAX = -1000.0
      RHO = RHO MIN
      M = NTR
      X = RHO - 1.0
600   CONTINUE
  700 IF (RHO.LE.X)  GO TO 720
      DO 710 L=1,3
      DO 710  J = 1,NRMODE(m)
      SOLN A(J,L) = (0.0,0.0)
      DO 710  K = 1,NRMODE(ntr)
      IF(M .NE. NTR) GO TO 35
      if(l .eq. 1) then
      SOLN A(J,L) = SOLN A(J,L)
     $                   +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
     $COSGAM     +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
     $COSPHI   +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
     $SINPHI)/(-s(ntr,k))
      else
      SOLN A(J,L) = SOLN A(J,L)
     $                   +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
     $COSGAM     +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
     $COSPHI   +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
     $SINPHI)
      endif
      GO TO 710
 35   continue
      if(l .eq. 1) then
```

```
      SOLN A(J,L) = SOLN A(J,L)
     $                         +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
     $COSGAM     +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
     $COSPHI   +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
     $SINPHI)
     $ *zexp(-IM*WAVENO*S(NTR,K)*XVAL(NTR+1))/(-s(ntr,k))
      else
      SOLN A(J,L) = SOLN A(J,L)
     $                         +A(M,J,K)*(XTRA(1,L,NTR,K)*F(1,NTR,K,1)*
     $COSGAM     +XTRA(2,L,NTR,K)*F(2,NTR,K,1)*SINGAM*
     $COSPHI   +XTRA(3,L,NTR,K)*F(3,NTR,K,1)*SINGAM*
     $SINPHI)
     $ *zexp(-IM*WAVENO*S(NTR,K)*XVAL(NTR+1))
      endif
  710 CONTINUE
      M = M + 1
      X = XVAL(M)
      if(m .gt. nrslab) x=1.0e6
      GO TO 700
C
720   CONTINUE
      tahy = (0.0,0.0)
      tahx = (0.0,0.0)
      DO J=1,NRMODE(m-1)
        IF(M-1 .eq. NTR) then
          TB =zexp(-IM*WAVENO*S(M-1,J)*RHO)
        else
          TB =zexp(IM*WAVENO*S(M-1,J)*(XVAL(M-1) - RHO))
        endif
        tahy = tahy+SOLN A(J,1)*TB*F(1,M-1,J,2)
        tahx = tahx+SOLN A(J,3)*TB*F(4,M-1,J,2)
      enddo
      tahy = tahy*CONST/DSQRT(DSIN(RHO/ERAD))
      tahx = tahx*CONST/DSQRT(DSIN(RHO/ERAD))
      tahyr=tahy
      tahyi=-im*tahy
      tahxr=tahx
      tahxi=-im*tahx
      phshy=datan2(tahyi,tahyr)
      phshx=datan2(tahxi,tahxr)
      amphy=dsqrt(tahyr*tahyr+tahyi*tahyi)
      amphx=dsqrt(tahxr*tahxr+tahxi*tahxi)
      beta=datan2(amphy,amphx)
      delta=phshy-phshx
      num=dsin(2.0*beta)*dcos(delta)
      den=dcos(2.0*beta)
      psi=0.5*datan2(num,den)*57.295779
      if(psi .lt. 0.0) psi=psi+180.0
      chi=90.0-psi
      ampy=10.0*dlog10(dmax1(1.0d-30,amphy*amphy)*1.0d12)
      ampx=10.0*dlog10(dmax1(1.0d-30,amphx*amphx)*1.0d12)
      R(ISUB) = RHO
      DBy(ISUB) = ampy
      DBx(ISUB) = ampx
      angchi(isub)=chi
      RHO = RHO + DEL RHO
      ISUB = ISUB+1
      IF (RHO .LE. RHOMAX) GO TO 600
```

```
      ISUB = ISUB-1
      PGAMMA = GAMMA/1.745329D-2
      PPHI = PHI/1.745329D-2
      PRINT 927,PGAMMA,PPHI,ZT,ZR
      PRINT 929
927   FORMAT(//,11X,'GAMMA(DEG)=',F6.1,'  PHI(DEG)=',F6.1,'  ZT(KM)=',
     $  F7.2,'  ZR(KM)=',F7.2)
929   FORMAT(/,13X,'RHO-KM',3X,'MAG(HY)-DB',3X,'MAG(HX)-DB',3x,
     $        'DOA ERROR-DEG')
      DO J=1,ISUB
        PRINT 908,R(J),DBy(J),DBx(J),angchi(J)
908     FORMAT(9X,F10.2,2x,F10.5,3x,F10.5,3x,F10.5)
      enddo
      write(*,'(/)')
      IF (iplflg.EQ.0)  RETURN
      CALL MCPLT2
      RETURN
      END
```

```
      SUBROUTINE MCPLTS
      parameter (maxmds=30)
C  MCPLTS GENERATES TWO PLOTS (FIELD AMPLITUDE IN DB ABOVE A
C  MICRO VOLT PER METER FOR 1 KW RADIATED POWER VERSUS TRANSMITTER-
C  TERMINATOR DISTANCE FOR TWO RECEIVER POSITIONS).
      COMMON/MCPLOT/R(400),DBy(400),DBx(400),ANGchi(400),
     $              IDPLOT(17),ISUB
      COMMON/XPLOT/XMIN,xmax,Xtic,YMIN,ymax,Ytic,SIZEX,SIZEY
      COMMON/HGINPT/GAMMA,PHI,ZT,ZR,SINGAM,COSGAM,SINPHI,COSPHI
      COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
     $             XTRA(3,3,25,maxmds),TOPHT(25),
     $             XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
     $             SIGMA(25),NRSLAB,NRMODE(25),NTMAX
      dimension xl(2),yl(2)
      COMPLEX*16 THETA,FOFR,XTRA
      REAL*8 XVAL,FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr,SIGMA,TOPHT
      REAL*8 SINGAM,COSGAM,SINPHI,COSPHI,GAMMA,PHI,ZT,ZR
      LOGICAL UP(400),upl(2)
c
      xinc=(xmax-xmin)/sizex
      yinc=(ymax-ymin)/sizey
      DO J=1,2
        upl(J)=.FALSE.
      enddo
      DO J=1,400
        UP(J)=.FALSE.
      enddo
      CALL pltbgn
      CALL plot(1.0,1.0,-3)
      call symbol(2.0,-0.5,.10,35HTransmitter-Terminator Distance(Mm),
     $            0.0,35)
      call symbol(-0.9,0.9,.10,26H    Bearing Error (Deg)   ,90.0,26)
      call symbol(-0.7,0.9,.10,35HAmplitude (dB above luv/m for 1 kW),
     $            90.0,35)
      CALL bordr2(sizex,XMIN/1000,xmax/1000,Xtic/1000,2.*Xtic/1000,1,
     $            sizey,YMIN,ymax,Ytic,2.*Ytic,-1)
      GAMMAD = GAMMA/1.745329D-2
      PHID = PHI/1.745329D-2
        xpos=0.0
        xstart=xmin
c
c       draw legend
        xl(1)=xstart
        xl(2)=xstart+xinc*0.7
        yl(1)=ymax+yinc*0.3
        yl(2)=ymax+yinc*0.3
        call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,2)
        call symbol(xpos+0.7,sizey+0.25,.1,6H  |HY|,0.,6)
c
        xl(1)=xl(1)+1.5*xinc
        xl(2)=xl(2)+1.3*xinc
        call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,4)
        xpos=xpos+1.5
        call symbol(xpos+0.5,sizey+0.25,.1,6H  |HX|,0.,6)
c
        xl(1)=xl(1)+1.5*xinc
        xl(2)=xl(2)+1.5*xinc
        call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,5)
```

```
      xpos=xpos+1 5
      call symbol(xpos+0.5,sizey+0.25,.1,14H Bearing Error,0.,14)
c
c     draw solid line at 0.0
      xl(1)=xmin
      xl(2)=xmax
      yl(1)=0.0
      yl(2)=0.0
      call curve(xl,yl,upl,2,xmin,ymin,(xmax-xmin)/sizex,
     $      (ymax-ymin)/sizey,1)
c
      CALL CURVE(R,dby,up,NTMAX,xmin,ymin,xinc,yinc,2)
      CALL CURVE(R,dbx,up,NTMAX,xmin,ymin,xinc,yinc,4)
      CALL CURVE(R,angchi,up,NTMAX,xmin,ymin,xinc,yinc,5)
      CALL symbol(0.0,sizey+1.3,.10,IDPLOT,0.0,68)
      CALL symbol(0.,sizey+0.9,.10,17HFreq =       kHz,0.0,17)
      CALL number(0.7,sizey+0.9,.10,sngl(FREQ),0.0,3)
      CALL symbol(3.5,sizey+0.9,.10,29HReceiver Distance =       km,
     $         0.0,29)
      CALL number(5.5,sizey+0.9,.10,sngl(rhomin),0.0,1)
      CALL symbol(0.,sizey+0.7,.10,29HZt =       km   Zr =       km,
     $         0.0,29)
      CALL number(0.50,sizey+0.7,.10,sngl(zt),0.0,2)
      CALL number(2.05,sizey+0.7,.10,sngl(zr),0.0,2)
      CALL symbol(3.5,sizey+.7,.10,
     $         35HGamma =       deg   Phi =       deg,0.0,35)
      CALL number(4.30,sizey+0.7,.10,gammad,0.0,1)
      CALL number(6.05,sizey+0.7,.10,phid,0.0,1)
      CALL pltend
      RETURN
      END
      SUBROUTINE MCPLT2
      parameter (maxmds=30)
C  MCPLT2 GENERATES ONE PLOT (FIELD AMPLITUDE IN DB ABOVE A MICRO VOLT
C  PER METER FOR 1 KW RADIATED POWER VERSUS DISTANCE FROM TRANSMITTER).
      COMMON/MCPLOT/R(400),DBy(400),DBx(400),ANGchi(400),
     $           IDPLOT(17),ISUB
      COMMON/XPLOT/XMIN,xmax,Xtic,YMIN,ymax,Ytic,SIZEX,SIZEY
      COMMON/HGINPT/GAMMA,PHI,ZT,ZR,SINGAM,COSGAM,SINPHI,COSPHI
      COMMON/MCINPT/THETA(25,maxmds),FOFR(25,maxmds),
     $           XTRA(3,3,25,maxmds),TOPHT(25),
     $           XVAL(25),FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr(25),
     $           SIGMA(25),NRSLAB,NRMODE(25),NTMAX
      dimension xl(2),yl(2)
      COMPLEX*16 THETA,FOFR,XTRA
      REAL*8 XVAL,FREQ,RHOMAX,RHOMIN,DELRHO,DELTAX,epsr,SIGMA,TOPHT
      REAL*8 SINGAM,COSGAM,SINPHI,COSPHI,GAMMA,PHI,ZT,ZR
      LOGICAL UP(400),upl(2)
c
      xinc=(xmax-xmin)/sizex
      yinc=(ymax-ymin)/sizey
      DO J=1,2
        upl(J)=.FALSE.
      enddo
      DO J=1,400
        UP(J)=.FALSE.
      enddo
      CALL pltbgn
```

```
      CALL plot(1.0,1.0,-3)
      call symbol(1.5,-0.5,.10,21HDistance (Megameters),0.0,21)
      call symbol(-0.9,1.5,.10,26H    Bearing Error (Deg)    ,90.0,26)
      call symbol(-0.7,1.5,.10,35HAmplitude (dB above 1uv/m for 1 kW),
     $             90.0,35)
      CALL bordr2(sizex,XMIN/1000,xmax/1000,Xtic/1000,2.*Xtic/1000,-1,
     $             sizey,YMIN,ymax,Ytic,2.*Ytic,-1)
      GAMMAD = GAMMA/1.745329D-2
      PHID = PHI/1.745329D-2
        xpos=0.0
        xstart=xmin
c
c      draw legend
        xl(1)=xstart
        xl(2)=xstart+xinc*0.7
        yl(1)=ymax-yinc*0.3
        yl(2)=ymax+yinc*0.3
        call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,2)
        call symbol(xpos+0.7,sizey+0.25,.1,6H  |HY|,0.,6)
c
        xl(1)=xl(1)+1.5*xinc
        xl(2)=xl(2)+1.3*xinc
        call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,4)
        xpos=xpos+1.5
        call symbol(xpos+0.5,sizey+0.25,.1.6H  |HX|,0.,6)
c
        xl(1)=xl(1)+1.5*xinc
        xl(2)=xl(2)+1.5*xinc
        call curve(xl,yl,upl,2,xmin,ymin,xinc,yinc,5)
        xpos=xpos+1.5
        call symbol(xpos+0.5,sizey+0.25,.1,14H Bearing Error,0.,14)
c
c       draw solid line at 0.0
        xl(1)=xmin
        xl(2)=xmax
        yl(1)=0.0
        yl(2)=0.0
        call curve(xl,yl,upl,2,xmin,ymin,(xmax-xmin)/sizex,
     $        (ymax-ymin)/sizey,1)
c
      CALL CURVE(R,dby,up,ISUB,xmin,ymin,xinc,yinc,2)
      CALL CURVE(R,dbx,up,ISUB,xmin,ymin,xinc,yinc,4)
      CALL CURVE(R,angchi,up,ISUB,xmin,ymin,xinc,yinc,5)
      CALL symbol(0.0,sizey+1.5,.10,IDPLOT,0.0,68)
      CALL symbol(0.,sizey+1.1,.10,17HFreq =        kHz,0.0,17)
      CALL number(0.7,sizey+1.1,.10,sngl(FREQ),0.0,3)
      CALL symbol(0.,sizey+0.9,.10,29HZt =       km   Zr =       km,
     $             0.0,29)
      CALL number(0.50,sizey+0.9,.10,sngl(zt),0.0,2)
      CALL number(2.05,sizey+0.9,.10,sngl(zr),0.0,2)
      CALL symbol(0.,sizey+0.7,.10,33HGamma =      deg   Phi =      deg,
     $             0.0,33)
      CALL number(0.80,sizey+0.7,.10,gammad,0.0,1)
      CALL number(2.45,sizey+0.7,.10,phid,0.0,1)
      CALL pltend
      RETURN
      END
```

```
      subroutine pltbgn
      character*1 answr
      logical first,autopl
      dimension ia(8),ibuff(2)
      data ia/82,79,57,48,73,87,73,80/
c ASCII        R  O  9  0  I  W  I  P
      data first/.true./,autopl/.false./
      if(first) then
        open(unit=52,file='/dev/plt7550a')
        print *,'If this is the hp 7550 plotter and you want auto feed,'
        print *,'then set up the plotter, load a sheet and answer y:'
        print *,'Do you want auto feed?'
        read 1, answr
1       format(a1)
        if(answr .eq. 'y' .or. answr .eq. 'Y') then
          autopl=.true.
        else
          autopl=.false.
        end if
      end if
      if(.not.autopl .or. first) then
        print *,'Set up plotter, enter rotation (y/n) when ready'
        read 1, answr
        first=.false.
      end if
      call hpinit(2,0,0,0,52)
      if(answr .eq. 'y' .or. answr .eq. 'Y')
     $  call buff(1,ia,xbuff,8)
      call newpen(1)
      return
      end
      subroutine plton
      dimension ia(3)
      data ia/27,46,89/
c ASCII      esc   .  Y
      call buff(1,ia,xbuff,-3)
      call newpen(1)
      return
      end
      subroutine pltend
      call newpen(0)
      entry pltoff
      call plot(0.0,0.0,999)
      return
      end
```

```
      subroutine bordr2(xlng,xmin,xmax,xticl,xtic2,ndx,
     $                 ylng,ymin,ymax,yticl,ytic2,ndy)
c
      xscale=xlng/(xmax-xmin)
      yscale=ylng/(ymax-ymin)
      if(xticl*xscale .le. 0. .or. xtic2*xscale .le. 0.) go to 999
      if(yticl*yscale .le. 0. .or. ytic2*yscale .le. 0.) go to 999
c
      if(iabs(ndx) .gt. 9) then
        sx=.15
        nx=ndx-(ndx/10)*10
      else
        sx=.1
        nx=ndx
      end if
      xo=.5*sx
      if(iabs(ndy) .gt. 9) then
        sy=.15
        ny=ndy-(ndy/10)*10
      else
        sy=.1
        ny=ndy
      end if
      yo=.5*sy
c
      xres=abs(xticl)/10.
      yres=abs(yticl)/10.
c
      tl=.05
      t2=.10
      yval=ymin
      ytc2=ymin
      xp=0.
      yp=0.
      go to 115
112   yval=yval+yticl
      if(abs(yval-ymax) .le. yres) then
        call plot(0.,ylng,2)
        if(abs(yval-ytc2) .le. yres) then
          xln=-sy*(3+ny)
          yln=ylng-yo
          if(abs(yval) .gt. yres .or. abs(yval) .ge. 10.)
     $      xln=xln-sy*aint(alog10(abs(yval)))
          if(abs(yval) .lt. yres) yval=0.
          if(yval .lt. 0.) xln=xln-sy
          call plot(xln,yln,3)
          call number(xln,yln,sy,yval,0.,ny)
        end if
        call plot(0.,ylng,3)
        go to 120
      end if
      yp=(yval-ymin)*yscale
      call plot(xp,yp,2)
      if(abs(yval-ytc2) .gt. yres) go to 118
        call plot(t2,yp,2)
115     xln=-sy*(3+ny)
        yln=yp-yo
        if(abs(yval) .gt. yres .or. abs(yval) .ge. 10.)
```

```
     $    xln=xln-sy*aint(alog10(abs(yval)))
          if(abs(yval) .lt. yres) yval=0.
          if(yval .lt. 0.) xln=xln-sy
          call plot(xln,yln,3)
          call number(xln,yln,sy,yval,0.,ny)
          ytc2=ytc2+ytic2
          go to 119
118     call plot(tl,yp,2)
119     call plot(xp,yp,3)
        if(abs(yval-ymax) .gt. yres) go to 112
c
120     yp=ylng
        tl=ylng-.05
        t2=ylng-.10
        xval=xmin
        xtc2=xmin+xtic2
122     xval=xval+xtic1
        if(abs(xval-xmax) .gt. xres) go to 123
          call plot(xlng,ylng,2)
          if(abs(xval-xtc2) .le. xres) xtc2=xtc2+xtic2
          go to 130
123     xp=(xval-xmin)*xscale
        call plot(xp,yp,2)
        if(abs(xval-xtc2) .gt. xres) go to 128
          call plot(xp,t2,2)
          xtc2=xtc2+xtic2
          go to 129
128     call plot(xp,tl,2)
129     call plot(xp,yp,2)
        if(abs(xval-xmax) .gt. xres) go to 122
c
130     xp=xlng
        tl=xlng-.05
        t2=xlng-.10
        ytc2=ytc2-ytic2
        if(abs(ytc2-ymax) .le. yres) go to 135
132     yval=yval-ytic1
        if(abs(yval-ymin) .gt. yres) go to 133
          call plot(xlng,0.,2)
          go to 140
133     yp=(yval-ymin)*yscale
        call plot(xp,yp,2)
        if(abs(yval-ytc2) .gt. yres) go to 138
          call plot(t2,yp,2)
135       ytc2=ytc2-ytic2
          go to 139
138     call plot(tl,yp,2)
139     call plot(xp,yp,2)
        if(abs(yval-ymin) .gt. yres) go to 132
c
140     yp=0.
        tl=.05
        t2=.10
        yln=-2.*sx
        xtc2=xtc2-xtic2
        if(abs(xtc2-xmax) .le. xres) go to 145
142     xval=xval-xtic1
        if(abs(xval-xmin) .le. xres) then
```

```
          call plot(0.,0.,2)
          if(abs(xval-xtc2) .le. xres) then
            xln=-xo*(2+nx)
            if(abs(xval) .gt. xres .or. abs(xval) .ge.  10.)
     $        xln=xln-xo*aint(alog10(abs(xval)))
            if(abs(xval) .lt. xres) xval=0.
            if(xval .lt. 0.) xln=xln-xo
            call plot(xln,yln,3)
            call number(xln,yln,sx,xval,0.,nx)
          end if
          call plot(0.,0.,3)
          return
        end if
        xp=(xval-xmin)*xscale
        call plot(xp,yp,2)
        if(abs(xval-xtc2) .gt. xres) go to 148
          call plot(xp,t2,2)
145       xln=xp-xo*(2+nx)
          if(abs(xval) .gt. xres .or. abs(xval) .ge.  10.)
     $      xln=xln-xo*aint(alog10(abs(xval)))
          if(abs(xval) .lt. xres) xval=0.
          if(xval .lt. 0.) xln=xln-xo
          call plot(xln,yln,3)
          call number(xln,yln,sx,xval,0.,nx)
          xtc2=xtc2-xtic2
          go to 149
148     call plot(xp,t1,2)
149     call plot(xp,yp,3)
        if(abs(xval-xmin) .gt. xres) go to 142
c
999     print 100,xlng,xmin,xmax,xtic1,xtic2,ndx,
     $            ylng,ymin,ymax,ytic1,ytic2,ndy
100     format('0Error in BORDR2:'/
     $         '0xlng, xmin, xmax, xtic1, xtic2, ndx = ',1p5e11.3,i5/
     $         '0ylng, ymin, ymax, ytic1, ytic2, ndy = ',1p5e11.3,i5)
        call pltend
        stop
        end
```

```
      subroutine curve(x,y,up,nrpts,xmin,ymin,xinc,yinc,line)
c
c x,y,up must be dimensioned at least nrpts
c xmin,ymin are x,y origin in user units
c xinc,yinc are x,y scales in user units per inch
c
c line=1:  solid
c      2:  long dash
c      3:  medium dash
c      4:  short dash
c      5:  dotted
c      6:  short + long dash
c      7:  short + short + long dash
c
      logical up,up1,up2
      dimension ipen(8),joc(7),x(nrpts),y(nrpts),up(nrpts)
      data ipen/2,2,2,3,2,3,2,3/,joc/18, 11, 14, 23, 32, 41, 16/
      data delr/.1/
c
      if(nrpts .le. 1) go to 99
c
      if(line) 1,2,3
1     kk=mod(line,7)+7
      go to 4
2     kk=0
      go to 4
3     kk=mod(line,7)
4     kk=kk+1
      jo=joc(kk)/10
      jc=joc(kk)-10*jo
      ip=ipen(jo)
c
      j=0
      dr=0.
      rho1=0.
      rho2=delr
      px1=(x(1)-xmin)/xinc
      py1=(y(1)-ymin)/yinc
      up1=up(1)
      if(.not. up1) then
c
c go to first position with pen up
        call plot(px1,py1,3)
        if(kk .eq. 6) then
          px2=(x(2)-xmin)/xinc
          py2=(y(2)-ymin)/yinc
          delx=px2-px1
          dely=py2-py1
          rho=sqrt(delx**2+dely**2)
          if(rho .eq. 0.) then
            dx 6=delx*.1
            dy 6=dely*.1
          else
            dx 6=delx*delr/rho*.1
            dy 6=dely*delr/rho*.1
          end if
          call plot(px1+dx6,py1+dy6,2)
        end if
```

```
      end if
c
      do 40 i=2,nrpts
      px2=(x(i)-xmin)/xinc
      py2=(y(i)-ymin)/yinc
      up2=up(i)
      if(up2) then
        dr=0.
        rho1=0.
        rho2=delr
        go to 39
      end if
      if(up1) then
c pen has been up, prepare to lower pen
        call plot(px2,py2,3)
        go to 39
      end if
      if(kk .eq. 2) go to 38
      delx=px2-px1
      dely=py2-py1
      rho=sqrt(delx**2+dely**2)
      rho1=rho1+rho
      if(rho2 .gt. rho1) go to 38
      delx=delx*delr/rho
      dely=dely*delr/rho
      dx 6=delx*.1
      dy 6=dely*.1
      if(dr .eq. 0.) go to 20
      dx=delx*dr/delr
      dy=dely*dr/delr
      px1=px1+dx
      py1=py1+dy
      go to 21
20    if(rho2 .gt. rho1) go to 38
      px1=px1+delx
      py1=py1+dely
21    call plot(px1,py1,ip)
      if(kk .eq. 6) call plot(px1+dx6,py1+dy6,2)
      j=j+1
      ip=ipen(jo+mod(j,jc))
      rho2=rho2+delr
      go to 20
38    call plot(px2,py2,ip)
      dr=rho2-rho1
39    px1=px2
      py1=py2
      up1=up2
40    continue
99    return
      end
```